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Management of Gas Engines

135 ILLUSTRATIONS

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POWER-GAS PRODUCERS
MANAGEMENT OF STATIONARY GAS ENGINES
MANAGEMENT OF GAS TRACTORS
MANAGEMENT OF AUTOMOBILE ENGINES
MANAGEMENT OF AEROPLANE ENGINES
MANAGEMENT OF MARINE GAS ENGINES
TROUBLES AND REMEDIES
POWER DETERMINATIONS

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed. At the end of the volume will be found a complete index, so that any subject treated can be quickly found.

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POWER-GAS PRODUCERS

CONSTRUCTION OF PRODUCERS

PRESSURE AND SUCTION TYPES

1. A **gas producer** as referred to in this Section is an apparatus for making gas with which to run a gas engine. The producer plant is located near the engine and consists of a producer or generator, cleaning devices for the gas, and a piping system. Some plants require a holder to store the gas. The generator is generally called the producer, but the plant as a whole is also sometimes called the producer.

The fuels used in gas producers are bituminous and anthracite coals, coke, lignite, wood, and crude oil. The advantages of a gas producer are that it enables a gas engine to be operated independently of a central gas plant, and generally at a lower cost than when using illuminating gas, or gasoline and other distillates from petroleum.

2. Types of Producers.—There are two general types of producers, known as *pressure producers* and *suction producers.* They are also classified as *up-draft producers, down-draft producers,* and *double-zone producers,* depending upon the direction of the draft through the fuel.

In a pressure-producer plant the gas is stored in a holder, usually at a pressure of from 2 to 3 ounces per square inch. In this type the air enters the producer under pressure which is produced either by a steam blast or a blower. The pressure type is generally used where more than one engine must be

supplied from one producer, and where the fuel works best with a forced draft.

In a suction producer the draft is caused by the suction of the engine. No gas holder is needed, as the gas is not generated in excess of that required by the engine. Generally, however, a small gas drum or tank is located in the suction pipe near the engine to steady the flow of gas.

3. Power Gas.—Power gas is a mixture of gases made by heating fuel in a producer, the heat being derived from the burning of some of the fuel itself while a mixture of air and

TABLE I

COMPOSITION OF POWER GAS MADE FROM BITUMINOUS AND ANTHRACITE COAL

Names of Gases in Mixture	Symbols	Percentage by Volume	
		Bituminous	Anthracite
Carbon monoxide......	CO	24.4	22.7
Carbon dioxide........	CO_2	4.8	5.5
Hydrogen............	H	11.6	15.5
Oxygen..............	O	.6	.3
Methane.............	CH_4	3.7	.0
Ethylene.............	C_2H_2	.1	.0
Nitrogen.............	N	54.8	56.0

steam is supplied to the fire. Table I gives the names and the percentage by volume of the individual gases in the mixtures forming power gases made from bituminous and anthracite coals. The table also shows the chemical symbols of the individual gases in the mixtures. Thus, C stands for carbon, H for hydrogen, N for nitrogen, and O for oxygen. Where two or more letters are written together, it means that the gas is composed of the elements that each letter represents. Thus, CO is carbon monoxide, which is composed of equal parts of carbon and oxygen chemically combined. Where a small figure is written after a letter it means that the gas contains the

number of parts of that element represented by the figure. Thus, CO_2, is carbon dioxide, which is a chemical union of one part of carbon and two parts of oxygen.

The useful gases in power gas are carbon monoxide, CO, hydrogen, H, methane, CH_4, and ethylene, C_2H_4. The carbon dioxide, CO_2, the nitrogen, N, and the oxygen, O, are not combustible. The carbon dioxide, CO_2, is a product from the fuel that is completely burned to furnish the heat, and the N and O come from the mixture of air and steam supplied to the fire. The carbon monoxide, CO, comes from the fuel that is highly heated but incompletely burned owing to the scant air supply, and the CH_4 and C_2H_4 make up the volatile matter distilled from the heated thick bed of fuel over the fire. The steam prevents clinkering of the ash. The high temperature in the incandescent fuel dissociates the hydrogen, H, and the oxygen, O, that form the steam; the hydrogen, H, enters the power gas as a useful element, while the oxygen, O, unites with the carbon, C, of the fuel, forming CO_2 and CO.

The average heating value per cubic foot of good quality power gases made from bituminous coals is about 150 B. T. U., and from anthracite coals 138 B. T. U.

PRESSURE GAS PRODUCERS

4. The general arrangement of a pressure gas producer is illustrated in Fig. 1. The boiler *a* generates steam at from 60 to 75 pounds pressure, the steam being conveyed to the injector *b* through the pipe *c*. In the injector, the steam is discharged through a small nozzle, and the issuing current draws with it a certain amount of air from the casing *d* surrounding the pipe *e*, through which the hot gases leave the producer *f*. Thus the injector serves merely to deliver a mingled stream of air and steam to the ash-pit *g* of the producer, beneath the grate.

The producer consists of a cylindrical shell made of steel plates and lined with firebrick. A hopper *h*, which is closed toward the atmosphere by a removable lid *i*, and against the interior of the producer by means of the bell *j*, conducts fuel

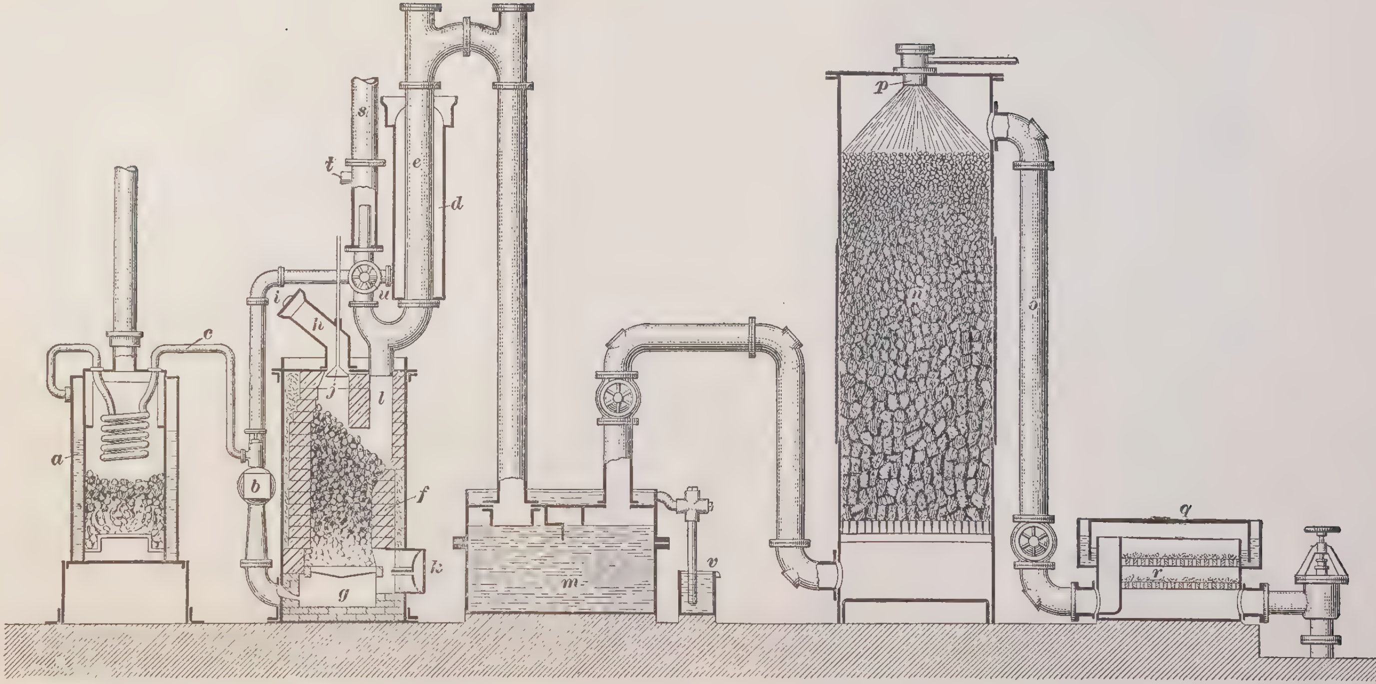


Fig. 1

to the producer while in operation. The bell being tight against its seat, the lid can be removed and the hopper filled with fuel. After closing the hopper, the bell is allowed to drop, permitting the fuel to enter the fire-pot of the producer, where it descends to the grate and is consumed, the ash and clinkers being removed through the door *k*.

5. The steam entering the producer is decomposed into oxygen and hydrogen while passing through the incandescent fuel. This oxygen, together with that which is in the air mixed with the steam, unites with the carbon of the fuel to form carbon dioxide and carbon monoxide. These gases mix with those produced from the fuel by the heat and pass upwards through the port *l* and the pipe *e*. The pipe *e* is provided with fittings having removable handhole covers, for the purpose of giving access in case it becomes necessary to clean the pipe. The gas is next forced through the water box *m*, where it is washed and most of the impurities removed; it then enters a wet scrubber *n*, which is filled with coke to within a few inches of the outlet pipe *o* near the top. As the gas rises in the scrubber, it is met by a descending shower of water distributed over the surface of the coke by means of the sprinkler *p*. The water cools the gas and carries away some of the impurities, leaving a portion deposited on the coke. The coke is placed in the scrubber with the larger pieces at the bottom, the sizes gradually diminishing toward the top, and need not be renewed for a period of from 1 to 2 years, according to the quality of the fuel used in the producer and the amount of tarry matter contained in the fuel. After the coke becomes clogged, the scrubber is emptied and fresh coke provided.

Any moisture, dust, or other impurities that the gas may contain after leaving the wet scrubber is removed while passing through the purifier box *q*—sometimes called a sawdust purifier or dry scrubber—which consists of a square box with a removable top and containing a series of wooden gratings *r*, over which are spread layers of sawdust, excelsior, or shavings. The gas is now ready to be stored in a holder, not shown in the

illustration, from which it is supplied to the engine in the same way as illuminating gas.

6. The gas generated when the producer is first started is of very poor quality and unfit for use. It is therefore permitted to escape into the atmosphere through the smoke and draft pipe *s*, until the gas burns with a bright blue flame at the test burner *t*. As soon as the quality has come up to the desired standard, the valve *u* in the draft pipe is closed, and the gas is allowed to pass on its way through the scrubber to the holder. The overflow from the water box *m* passes through the water seal *v*, which permits the water to flow to the sewer without allowing any gas to escape.

It will be seen, by an examination of Fig. 1, that all pipes between the producer and the holder are provided with fittings having handholes and covers, so that the pipes can be cleaned as occasion may require. These provisions are necessary, because when using the poorer grades of coal, some of the impurities contained in the gas will adhere to the walls of the pipes, and in time sufficient quantities may accumulate to interfere with the flow of the gas.

The pressure of the gas at the point where the injector *b* connects to the ash-pit of the producer is about 8 inches of water. This pressure gradually diminishes on account of the resistance that the gas encounters in its passage from the producer to the holder. Measured by a water gauge, the pressure in the pipe *e* between the producer and the water box is equal to about 6 inches; after leaving the scrubber, the pressure is 4 inches, and before entering the holder it is 2 inches.

7. Some soft coal, when being burned in a gas producer, fuses and tends to form a solid mass that obstructs the passage of air through the fuel, causing it to form channels through the fuel and thus to blow directly to the offtake without aiding in the combustion. In order to prevent the compacting of the fuel bed and the formation of air channels, producers using soft coal require a great deal of poking, which is not only heavy but tedious work. The producer shown in Fig. 2 has been developed to eliminate hand poking as much as possible.

The poking is done by the poker *a*, which is driven by the connecting-rod and ratchet mechanism *b* so that it moves back and forth about the shaft *c*. The body of the producer is rotated by the gearing *d* and the big gear *e*, while the poker is

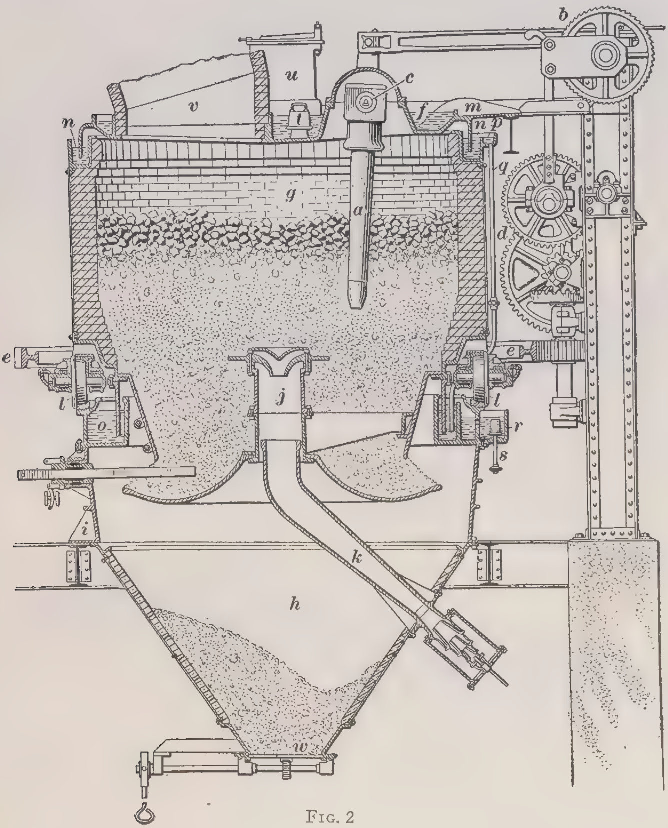


FIG. 2

moved back and forth from a point near the middle of the producer to one near the lining so that the whole fuel bed is thoroughly stirred at regular intervals.

8. The producer is built in three main parts, the water-cooled top *f*, the brick-lined body *g*, and the ash hopper *h*. The ash hopper is supported on the framework of the building by lugs, one of which is shown at *i*. The steam-and-air blast for

the maintenance of combustion in the producer is introduced through the blast tube *j* by the steam jet blower *k*, which will be described more fully later. The body *g* of the producer is mounted on wheels, two of which are shown at *l*. The top plate is attached by arms *m* to the framework of the building so the body of the producer rotates between the top plate and the ash hopper, both of which remain stationary. The top and bottom of the producer body are water sealed to prevent the leakage of gas. The top water seal is shown at *n* and the bottom one at *o*. The casting in which the upper water seal is formed has a number of cups such as *p* formed around its edge so that any water that is not required to maintain the seal overflows into these cups and flows from them through pipes *q* into the lower water seal. A number of cups *r* receive the overflow from the lower water seal and discharge it through the waste pipe *s*.

9. Observation holes, one of which is shown at *t*, are provided in the top plate. Each of these holes is provided with a flange extending somewhat above the level of the water and the hole is closed by a cup-shaped cap that fits over this flange. The edge of this cap dips into the water, so the hole is water sealed when the cap is in place. The observation holes permit the operator to watch the interior of the producer and to determine when fresh fuel is needed and, when hand poking is required, the poker may be inserted through one of these holes. There are two hoppers, one of which is shown at *u*, through which fuel is introduced into the producer. The arrangement by which the leakage of gas through the charging hoppers is prevented resembles that explained in connection with Fig. 1. The gas leaves the producer through the offtake *v* and the ash is drawn from the hopper *h* through the ash gate *w*.

10. The poke bar and part of the top plate are shown in section in Fig. 3. The poke bar *a* is a hollow steel casting with a forged steel point *b*. The steel point extends into the fire and it is therefore not only exposed to a high temperature but also subjected to a severe abrasive action as it moves through the fuel. The bar is therefore built so that it can be turned

around to bring the wear at different places and thus increase the service, and also so that it can be replaced when worn out. The point of the bar is usually the first part to wear out and it is consequently made so that it can be renewed. The poke bar and the point are both made hollow so that they can be cooled by circulating water through them, and the bad effects of the heat on them may thus be reduced. The cooling water

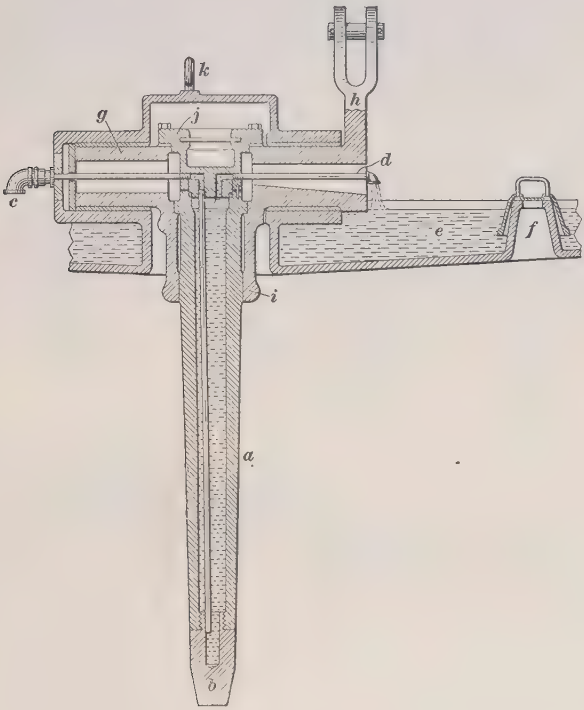


FIG. 3

enters from a pipe connected at the swing joint *c* to the piping that leads down inside of the bar to the point, and returns inside of the bar to the discharge pipe *d*, from which it falls into the producer top plate, part of which is shown at *e*. After a sufficient depth of water to cool the top plate properly has collected, the excess flows over the rim at one side and falls into the top water seal and from there it goes, as already

described, to the lower water seal and to waste. One of the observation holes with its water-sealed cap is shown at *f*.

11. The hollow shaft *g* and the crank *h* are made in one piece. The shaft has a hub *i* to hold the poke bar, which is held in place by the cap *j*. The poke bar and the housing that encloses its upper end may be removed from the producer

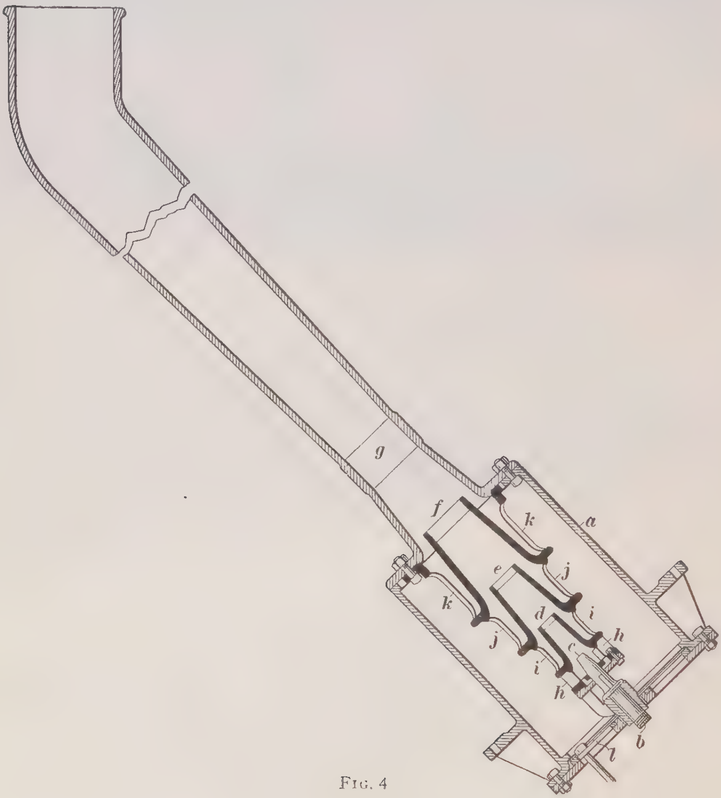


FIG. 4

when bolts, that are not shown, are removed, and the hole in the top plate is then closed by a temporary cover. The eye *k* is provided to give a convenient crane hold when lifting the poker mechanism.

12. The blast for the maintenance of the fire in the producer is developed by the steam blower shown in Fig. 4. This

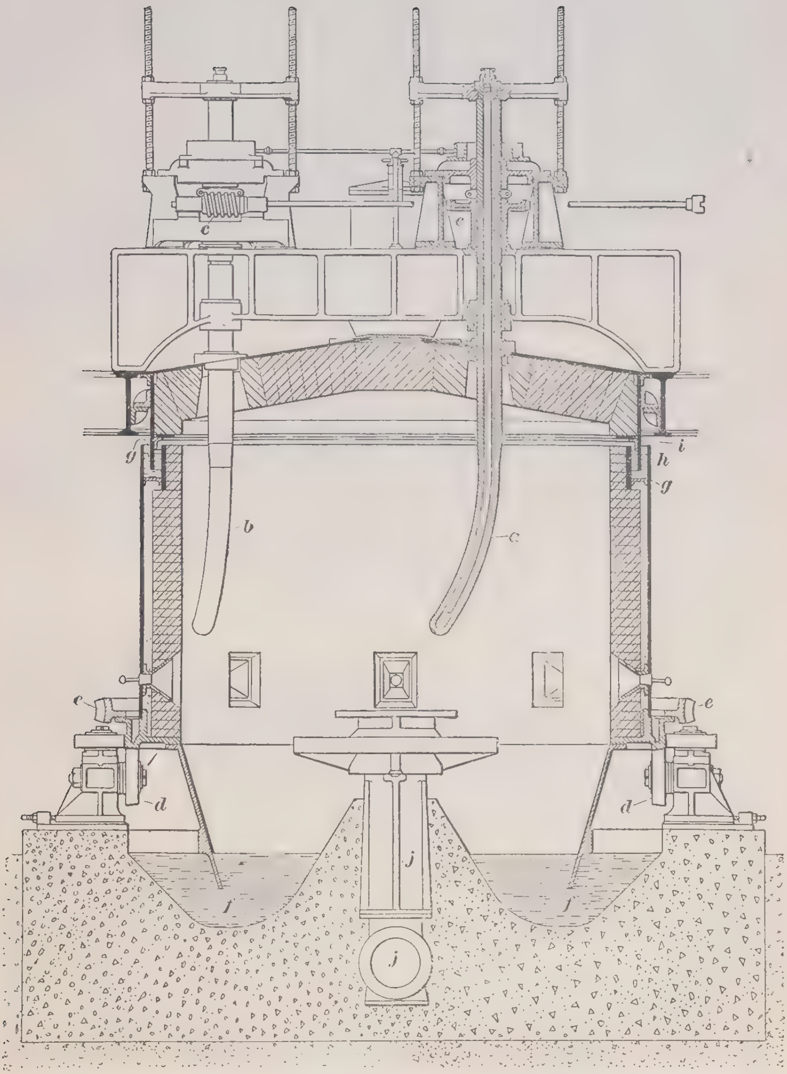


FIG. 5

blower consists of a wind box *a* to which five nozzles are attached. Steam enters the blower through the pipe *b* and issues from the nozzle *c* and then passes through nozzles *d, e, f,* and *g*. As the steam passes through each of these nozzles a quantity of air is drawn in through openings *h, i, j,* and *k* and goes with the steam into the producer. Air enters the wind box through an opening controlled by the damper *l,* which is also used to control the amount of air that is mixed with the steam. Increasing the quantity of air up to the point where combustion is complete, tends to make the fire in the producer hotter, and increasing the quantity of steam admitted, tends to reduce the temperature of the fire. It is, therefore, necessary to proportion the air and steam by means of the damper *l* so as to maintain the proper working temperature in the producer.

13. Another arrangement for mechanically stirring the fuel in a pressure generator is shown in Fig. 5. In this case two water-cooled pokers, or stirrers, *a* and *b,* are inserted through gas-tight boxes in the stationary covers, one near the middle and one near the edge. The stirrers are slightly curved at the lower end, and they are arranged so that they may be raised or lowered readily; they are revolved by power acting through worm gearing *c*. The body of the generator is supported on rollers *d,* and it is revolved by means of a large worm gear *e*. This movement together with the motion of the stirrers keeps the fuel quite evenly distributed and broken up.

The bottom water seal *f* is in the ash-pit, which permits the ash to be removed without letting in an oversupply of air. The top water seal *g* consists of a trough *h* in the upper part of the body, and a flange *i* extends downwards from the circumference of the stationary cover into the trough. The air for combustion, and the steam or water vapor enter through the central flue *j* in the bottom.

SUCTION GAS PRODUCERS

14. Comparison of Suction and Pressure Producers.—The processes of generating and purifying the gas are the same in the pressure and suction types of producers; but in the pressure producer a pressure above that of the atmosphere is maintained by a forced draft, either from a low-pressure steam boiler or from a blower; while in the suction producer the pressure in any part of the apparatus or its connections is never higher than that of the atmosphere. The draft in the suction producer is furnished by the engine piston during the suction stroke while the inlet valves are open, and the vacuum created in the cylinder causes the gas from all parts of the producer apparatus to flow toward the engine.

The difference in pressure between the two systems is practically 8 inches of water; so that, in the suction producer, the pressure of the gas as it leaves the scrubber is about 6 inches of water below atmospheric pressure instead of 2 inches above, as in the case of the pressure producer. The relative difference in pressure in the various parts of the apparatus is the same in both systems, and the order of the operations of the process is necessarily alike in both cases. The suction type of producer does not require a large gas holder, a small cast-iron or sheet-metal tank being used instead. This tank is but slightly larger than the customary gas bag or pressure regulator used in connection with engines using illuminating gas.

15. Supply of Air and Moisture.—A suction gas producer of small capacity, in which the evaporator for supplying the necessary moisture to the air is mounted directly above the producer shell, is shown in Fig. 6. The apparatus consists of the producer *a* with a cast-iron shell; the hand-operated blower *b*, for reviving the fire after a shut-down; the evaporator *c*; the hopper *d*; the water trap *e*; the water-seal box *f*; the scrubber *g*; and the gas tank, or reservoir, *h*. At each suction stroke of the engine, air is drawn into the top of the evaporator *c*, through the elbow *i*, which is open to the atmos-

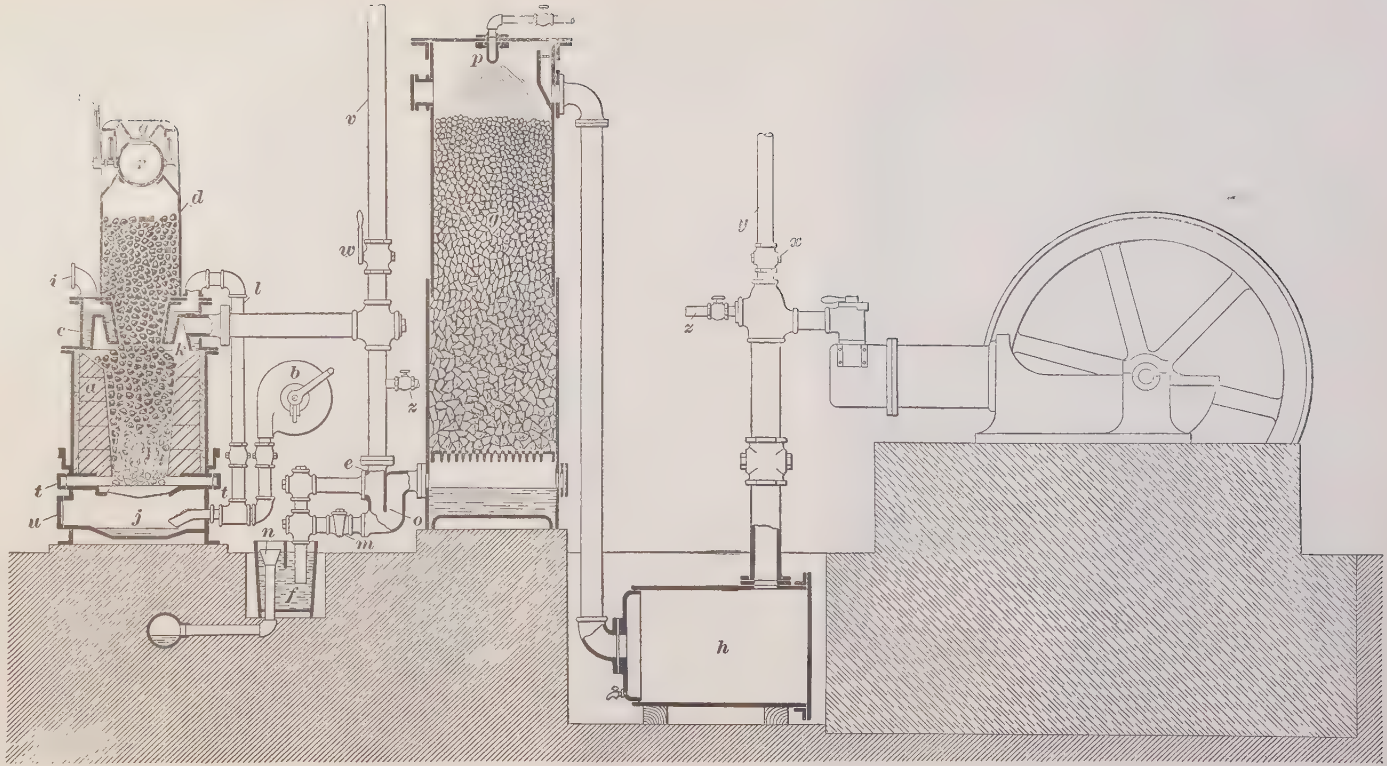


FIG. 6

phere. The evaporator is filled with water from a branch pipe taken from the main supply pipe and kept at a constant level by an overflow pipe, not shown in the illustration, that carries any surplus supply to the ash-pit *j*. The water in the evaporator is heated to about 170° F. by radiation from the burning fuel and by the hot gases that leave the producer through the port *k*.

The air passing over the surface of the hot water absorbs a quantity of vapor, the amount depending on the temperature of the water; so that the quantity of the water vapor admitted with the air through the pipe *l* to the space below the grate is greater when the fire is hot than when it is low. The fire is hottest, of course, when the engine is carrying a heavy load. Under heavy load, not only does the increase in the amount of vapor enrich the quality of the gas generated, but also the moistened air has a correspondingly greater cooling effect on the grate and tends to keep the fire at a proper degree of intensity.

16. After entering the ash-pit the mixture of air and steam is drawn upwards through the hot bed of fuel, where the steam is decomposed into hydrogen and oxygen, and the formation of carbon monoxide takes place. After transferring a portion of its heat to the water in the evaporator, the gas leaves the producer through the port *k*, passes through the water trap *e*, and enters the scrubber at the bottom. The water trap has two pipe connections to the water-seal box *f*, the lower pipe being provided with a valve *m*. While the plant is in operation, this valve is open and the water that accumulates in the bottom of the scrubber flows through the lower connection to the seal box *f* and thence through an overflow funnel *n* to the sewer. When the plant is shut down, the valve *m* should be closed, thus causing the water in the trap *e* to rise well above the lower end of the partition wall *o*. This closes the gas connection between the producer and the engine. Any excess of water then flowing to the seal box passes through the upper pipe attached to the trap *e* and thence to the sewer.

17. Passage of Gas Through Scrubber.—While the gas is rising through the coarse coke in the scrubber *g*, it is met by a descending stream of cold water which is distributed evenly over the surface of the coke by means of the sprinkler *p* attached to the top cover-plate. In this manner, the gas, from which some of its impurities have been removed while passing through the trap *e*, is now cooled and washed sufficiently to be delivered to the gas tank *h* in such condition that it contains no tarry or dusty substances to interfere with the successful running of the engine. When semianthracite or similar fuels containing higher percentages of tarry matter than pure anthracite or charcoal are used, it is necessary to add a sawdust purifier or dry scrubber similar to that used in connection with the pressure producer shown in Fig. 1.

18. Supplying the Fuel.—The fuel is supplied to the producer shown in Fig. 6 through the charging device mounted above the hopper *d*, which consists of the funnel *q* and a smooth hollow ball *r* that can be turned on its ground seat by the hand lever *s*. The ball has an opening at the top, so that it may be filled with coal through the funnel, after which it is turned over by a quick movement of the hand lever, bringing the opening in the ball in communication with the coal space in the hopper *d*. As soon as the ball has thus been emptied of its contents, it is turned back and the operations of filling and emptying are repeated until the hopper is filled to the desired height. When not in use for filling the producer, the ball is held tightly on its seat with screws and hand nuts. The quick turning of the ball leaves but a small part of a second during which the hopper is open to the atmosphere, and practically no air is admitted to the producer at that point.

19. Removing Ash and Clinkers.—The removal of clinkers from the fire space of the producer is facilitated by poke holes that permit the fire to be stirred from above with suitable poking bars. The clinkers that drop to the grate are removed through the two fire-doors *t*, on opposite sides of the producer shell, while the ash accumulating in the pit below the grate is drawn out through the ash door *u*.

20. Starting the Suction Producer.—The hand-operated blower *b* serves to supply the blast necessary to start up the fire after the plant has been shut down for a time. During a temporary shut-down, the process of gas making is practically stopped, except for the small amount of gas generated by the natural draft through the draft pipe. This pipe is opened to the atmosphere by turning the valve *w*. While reviving the fire, the valve *w*, as well as the valve *x* in the vent, or purge, pipe *y*, is kept open until the gas escaping at the test tubes *z*, *z*—one of which is placed in the pipes between the producer and the scrubber, and the other near the inlet to the engine—is of such quality as to burn with a bright blue flame. The valve *w*, and the valves in *z* and *z* are then closed and the engine is started in the usual manner. To secure prompt starting, it is found advisable to keep the valve in the vent pipe *y* open to the atmosphere until a few explosions have taken place in the engine cylinder, and then close it.

LARGE-CAPACITY SUCTION PRODUCER

21. A suction producer of larger capacity than the one shown in Fig. 6 and equipped with a separate evaporator is shown in Fig. 7. Instead of the cast-iron body shown in Fig. 6 in connection with the smaller type, the producer *a* consists of a shell built of steel plate and lined with fire-brick; but the hopper *d* and the coal-feeding device *r* are made of cast iron, and are essentially of the same construction as in the smaller producer. Instead of a hand blower, a belt-driven pressure blower *b* furnishes the draft for starting.

The essential difference between the larger and the smaller plant is that the evaporator for heating the water in the smaller plant forms a part of the generator, while in the large plant it is a separate piece of apparatus and is connected to the generator by pipes. In the case of the larger, Fig. 7, the evaporator consists of a cylindrical casting *c* with a hood *e* having a vertical dividing wall in the center, so that the air entering through the pipe *f* will be forced over the surface of the hot water in the evaporator before it passes to the ash-pit of the

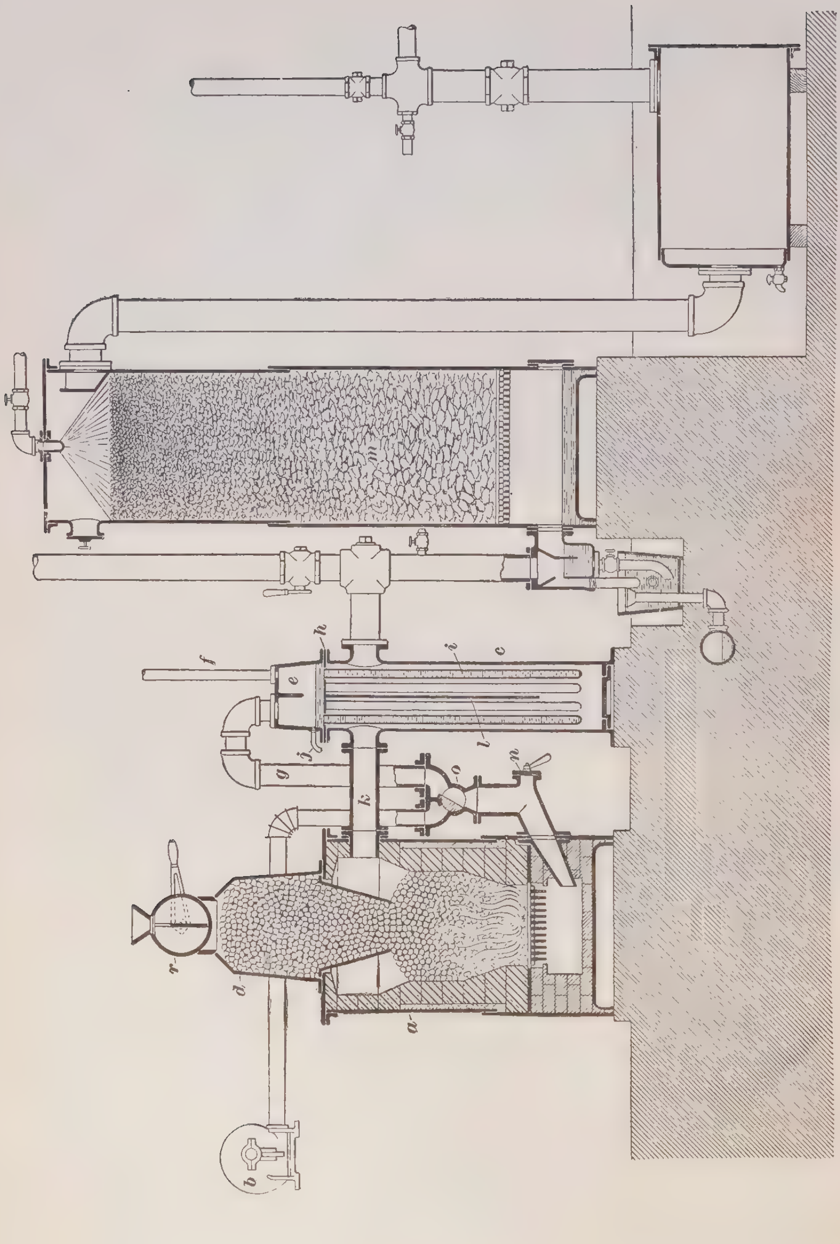


FIG. 7

producer through the pipe *g*. Between the evaporator cylinder *c* and the hood, a plate *h* carrying a number of vertical tubes *i* is clamped. The tubes are kept full of water, which is maintained at the proper level slightly above the upper surface of the plate *h* by an overflow pipe *j*. The hot gases leave the producer through the pipe *k*, and pass downwards and then upwards in the evaporator, being guided by the vertical partition *l*, and finally pass on to the scrubber *m*. In this manner, the water in the tubes is kept hot, so that the required amount of vapor is taken up by the air while passing through the hood *e* to the ash-pit of the producer.

In order to be able to control the amount of moist and dry air used, a regulating plate *n* is provided in the air pipe, by means of which the air-supply pipe can be opened to any desired extent to the atmosphere in the producer room, thus admitting cool air that has not come in contact with the hot water. The three-way valve *o* serves to shut off the air connection to the evaporator when the fire is being revived by the blast from the blower. As soon as the gas has become of good quality, the blower is stopped and the three-way valve set so as to admit air in the regular way through the pipe *g*.

COMBINED PRODUCER AND EVAPORATOR

22. Another suction gas producer of somewhat different design is shown in Fig. 8. The producer consists of a cylindrical steel shell lined with firebrick and fitted with a shaking grate *a* operated by the hand lever *b*. The hopper *c*, through which fuel is supplied to the producer, is sealed by the charging device *d*, so that any fuel placed in it can be admitted to the hopper without permitting air to enter the producer. From the hopper, the fuel descends into the fire-space through the feeding tube *e* surrounded by the evaporator *f*, in which the necessary steam is generated at atmospheric pressure by the heat of the fire and of the gases when leaving the producer.

23. The ash is removed from the ash-pit *g* through the door *h*. A series of poke holes *i* distributed over the top of the producer permit rods to be inserted for the purpose of

poking the fire and removing clinkers from the walls of the lining. Dry air is admitted to the ash-pit through the supply pipe *j*, while moist air, which is saturated with steam from the evaporator, is supplied to the ash-pit through pipes *k*, air

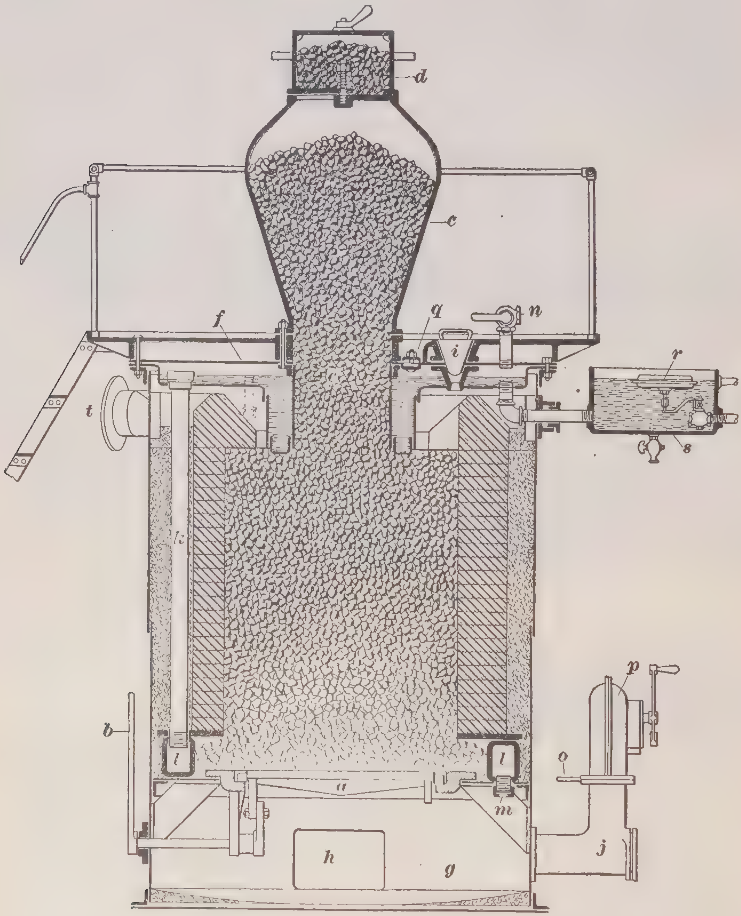


Fig. 8

boxes *l*, and nipples *m*. The air enters the top of the evaporator through the valve *n*. The proportionate amounts of dry and moist air can be regulated as desired by opening or closing the valves *n* and *o*. The hand-operated blower *p* is used for

starting or reviving the fire. Handholes *q* in the top of the evaporator are provided for the purpose of removing any sediment that may accumulate in the bottom of the evaporator. The water supply to the evaporator is automatically regulated by the float *r* that controls a valve in the water box *s*. The water rising in the box raises the float and closes the valve,

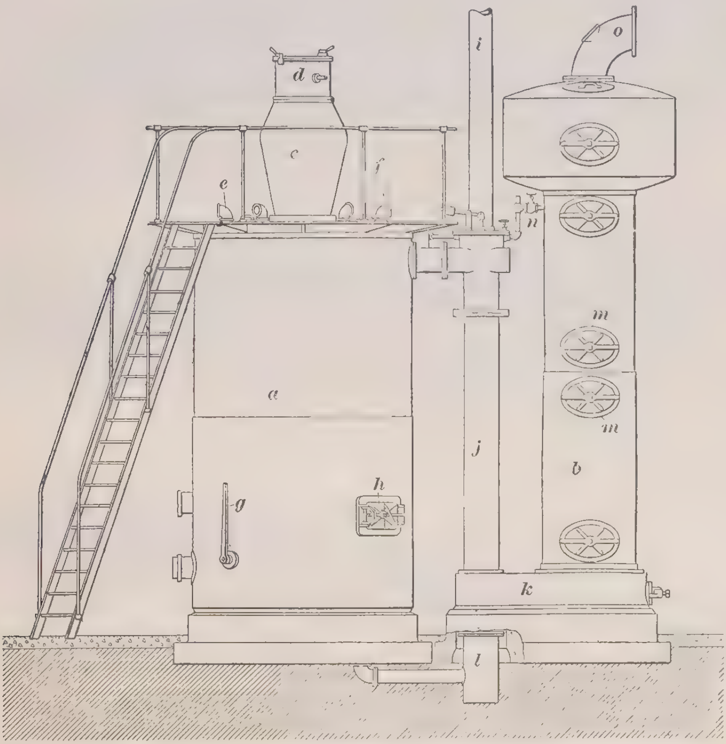


Fig. 9

while the lowering of the float opens the water valve. The gas passes from the producer to the scrubber through the pipe *t*, which is connected to the top of the producer.

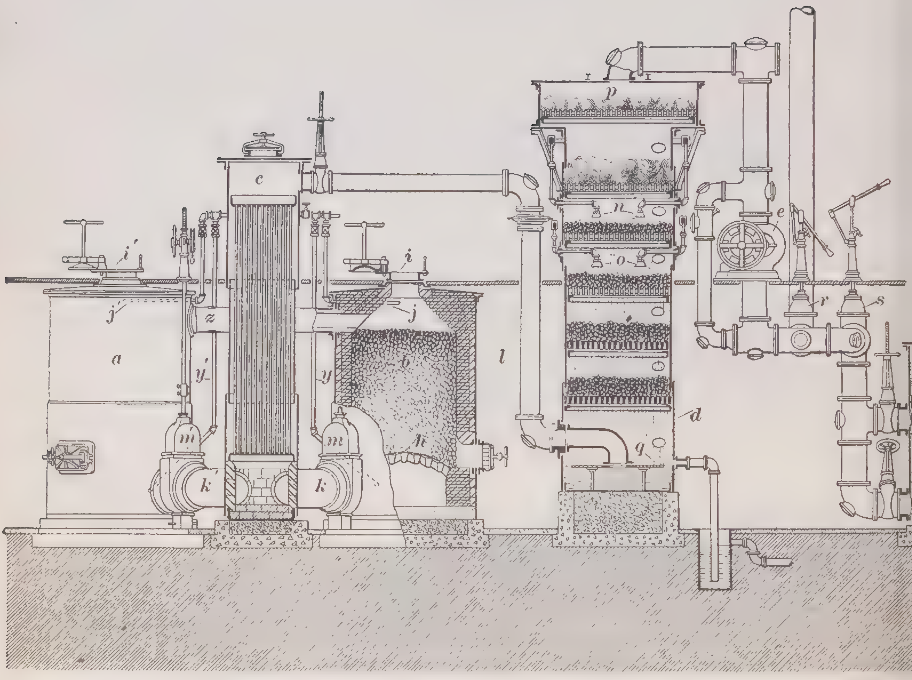
24. An outside view of a producer of this type, connected to its scrubber, is shown in Fig. 9. The producer is shown at *a* and the scrubber at *b*. The hopper *c* with the filling device *d* is located over the producer and is readily accessible by the

stairs and the platform around the top of the producer. The fittings *e* admit the air to the evaporator, and the handles *f* are connected to the covers of the openings through which the fire is poked. The handle *g* is provided for the purpose of rocking the grate, and the door *h* gives access to the fire. The draft or smoke pipe is shown at *i* and the main gas pipe at *j*, connected to the scrubber at *k*, with the water trap *l* extending below the scrubber. There are a number of manholes *m* on the side of the scrubber, to permit easy access to the interior. The water connections are shown at *n*, and the gas outlet from the scrubber at *o*.

DOWN-DRAFT PRODUCER

25. A gas-producer plant in which the draft is furnished by an exhaust fan operated by a small motor, drawing the gas from one scrubber and forcing it through another into a gas holder, is shown in Fig. 10. This apparatus consists of two similar generators *a* and *b*, an evaporator *c*, a wet scrubber *d*, an exhaust fan *e*, a dry scrubber *f*, and the gas holder *g*. The gas generators are of the *down-draft type*, which is considered especially adapted to the use of fuels containing tarry matter, such as bituminous coal, wood, etc. The gas and tarry substances produced by the fresh fuel in the upper portion of the producer, pass down through the incandescent fuel bed, where they are heated to a very high temperature, and a gas free from tar is thus formed. Tar in producer gas remains gaseous only so long as it is at a comparatively high temperature. When the gas is cooled, the tar condenses and separates from the gas in the mains or scrubber, thus reducing the heating value of the gas and fouling the gas mains and scrubber. When tar is heated to a sufficiently high temperature, it is broken up into substances that remain gaseous at the lowest temperature to which producer gas is usually cooled. The heating value of tar in the gas is thus retained and the trouble caused by the fouling of the gas mains and scrubber is avoided.

26. The generators consist of cylindrical steel shells lined with firebrick and provided with firebrick arches *h* that sup-



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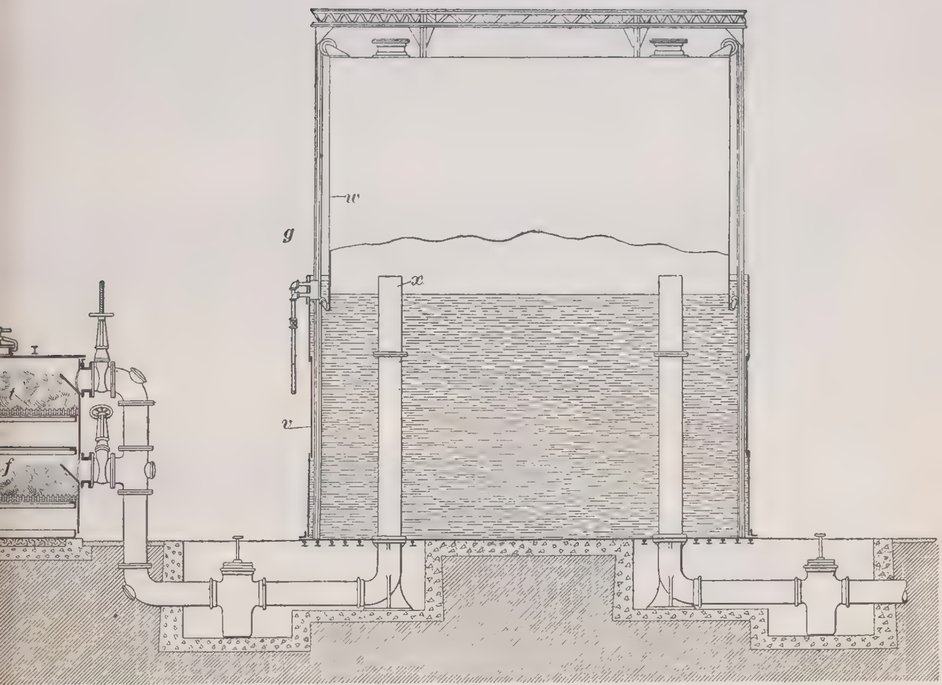

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port the fuel beds. Openings *i*, *i'*, at the tops of the generators, serve for charging fuel, and for the admission of air, and the usual fire and ash doors are provided for cleaning the arches and for the removal of the ash. Steam jets *j*, *j'*, one in each generator, are supplied from the boiler *c*. The boiler is of the vertical type, and is connected by brick-lined flues *k*, *k'*, to the bottoms of the generators, the passages being controlled by water-cooled valves *m*, *m'*. The hot gases leave the generators at the bottom, pass through the evaporator, and impart a portion of their heat to the water contained in the space around the tubes. The steam produced is directed into the top of the fire by the jets *j*, *j'*. The hot gases pass up through the tubes to the outlet pipe.

27. The wet scrubber *d*, consisting of a cylindrical steel shell, contains a number of trays filled with coke moistened by the water sprays *n* and *o*. A purifier *p* filled with excelsior is attached to the top of the scrubber. The gas-inlet pipe *l* at the bottom of the scrubber is attached to a horizontal perforated diaphragm *q* submerged in water, so that the gas must pass through the water before rising in the scrubber.

28. The fan or exhauster *e* maintains the necessary vacuum required to furnish the proper amount of draft and give sufficient pressure to deliver the gas to the holder. The motor that drives the exhauster is connected to the gas holder in such a way that the speed is automatically regulated, by the movement of the holder, to conform to the demand for gas. When the holder is full, the speed of the exhauster is decreased; while in descending, as the gas is consumed, the motor speed is increased, creating a correspondingly stronger draft and a greater production of gas. The direction in which the gas flows after being delivered by the exhauster is controlled by the valves *r* and *s*. The valve *r* is connected to the waste-gas pipe and is kept open to the atmosphere while the fire is being started or revived. As soon as the gas becomes of the proper quality, the valve *r* is closed and the valve *s* opened, so that the gas can pass to the dry scrubber *f* and holder *g*.

29. The dry scrubber contains two trays *t*, *t′* filled with excelsior, sawdust, or shavings. A horizontal partition *u* divides the scrubber into an upper and a lower chamber. Valves are provided so that either the upper or the lower chamber can be connected to or shut off from the gas supply for the purpose of cleaning and recharging the trays, without interrupting the operation of the apparatus. From the dry scrubber, the gas passes to the gas holder *g*, which consists of a stationary tank *v*, filled with water, and an inverted movable tank *w*, which fits inside the water tank. The gas enters the holder through the pipe *x*, whose upper end is slightly above the level of the water in the tank *v*.

As the amount of gas in the holder increases, the movable tank *w* rises, giving additional space for the gas between the water surface and the top of the tank *w*. When the volume of gas in the holder decreases, the tank *w* descends. The pressure of the gas in the holder is thus kept constant. The lower edge of the tank *w* is always submerged, forming a water seal that effectually prevents the escape of gas.

30. While the apparatus is in operation, the generators *a* and *b* are open at the top, so that the attendant can observe the condition of the fire and add fresh fuel where needed. Continuous operation of the producers in this way would develop too hot a fire, which would be unnecessarily destructive to the producer lining and would generate gas of inferior quality. When the fire in one of the producers gets so hot that it must be cooled, the direction of the draft is reversed for a time. Suppose that producer *a* is to be worked with up draft; the cover *i′*, steam jet *j′*, and valve *m′* are closed and steam is turned on through the pipe *y′* to a blower below the fire arch. The steam cools the fire and forms a combustible gas that passes through the cross-over pipe *z* to the space above the fire in producer *b* and then takes the usual course through that fire, the vaporizer, etc., to the gas holder. Any tar that may be in the gas from producer *a* is thus transformed into a permanent gas in producer *b*. The draft may be made to pass up through *b* and down through *a* by setting valves properly.

Should wood be used as fuel, the generators are filled with coke to a height of 3 or 4 feet above the arches *h*, and wood in lengths of 2 or 3 feet—or of ordinary cordwood size, 4 feet in length, if the generators are large—is placed on top of the coke. The wood is ignited, and the gas is delivered to the scrubbers and holders in the usual manner. No steam is admitted at the top, however, as the wood usually contains a sufficient amount of moisture to render the gas of proper quality.

DOUBLE-ZONE PRODUCER

31. A double-zone producer is intended for the gasification of coal that contains considerable volatile matter. In a double-zone producer, two fires are employed for the generation of the gas, one at the top and one at the bottom. In this double combustion process, the coal in the upper layers is partly burned and transformed into coke. The gases from the upper layers pass through an incandescent zone where the unstable gases are changed to fixed gases. The coke formed passes downwards and is completely burned in the lower fire. The gases formed below are stable, and are drawn off together with those from above.

A double-zone producer is shown in section in Fig. 11. The shell *a* consists of two parts approximately rectangular in shape, and is made of steel plate with firebrick lining *b*. The upper and the lower parts of the producer are separated by the vaporizer *c*, which supports the walls of the upper part of the producer, generates the steam necessary for the operation of the producer, and forms recesses that lead to the openings at *d* from which the gas is taken. Coal is put in at *e* through the water-cooled cover-plate *f*. This producer operates on the suction principle, and air will therefore leak into it whenever possible. The air and steam needed for the production of gas enter through pipes, at the top and bottom, that are not shown, and the amount of air and steam is controlled by suitable valves. The producer rests on columns *g* that support the mantel *h* on which the brick lining is built. The lower part *i*, called the bosh, extends into

the water-filled ash-pit j, so that the bottom of the producer is sealed against leakage of air but the ash k can be removed. The suction in the producer causes the water inside of the bosh to rise to l, somewhat higher than on the outside. The ash is removed from the ash-pit below the edge of the bosh, care being taken to keep the top of the bed of ash level and at a proper height. The position of the surface of the ash bed and of the fire may be observed through a series of openings provided at intervals around the producer. Two of these observation holes are shown at m and n. Other holes through which to watch the fire and to poke it when the fuel bed needs leveling or clinkers have to be loosened are provided at o and p.

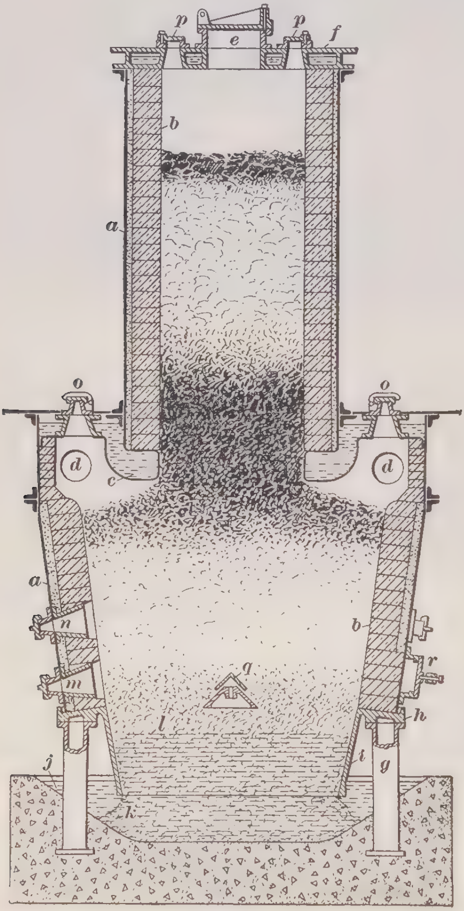

Fig. 11

JOINTS IN A PRODUCER PLANT

32. Special care is demanded in making the joints in a producer-gas plant. If the plant is of the pressure type, the leakage will be from the system. Producer gas contains large quantities of carbon-monoxide gas, which is especially dangerous to persons breathing it, and the safety of the workmen

therefore requires great care to prevent the leakage of gas. If the plant is of the suction type, air will tend to leak into the system. If air leaks into the producer or the pipes where the temperature is sufficiently high to cause ignition, more or less of the gas will be burned and wasted. When air leaks into the system of pipes when the temperature is not high enough to cause ignition, it dilutes the gas and may form an explosive mixture. The joints in a producer-gas plant should therefore be made with the greatest of care.

The manner of making joints depends on such conditions as the temperature to which the joint is exposed, the pressure that tends to cause the leakage of air or gas, and the permanency of the joint. The joints in a producer plant are of four classes, as follows: (1) Joints in the producer shell or piping that must be tight against pressure or suction tending to produce leakage of gas or air and are exposed to a high temperature. (2) Joints that must be tight against gas pressure or suction, but are not exposed to a very high temperature. (3) Joints that are subjected to gas pressure or suction, but need not be absolutely tight. (4) Miscellaneous joints not mentioned in the foregoing. Most of these joints can be made in a number of different ways, but the methods given here may be considered representative of good modern practice.

33. Most producers have at least a small place somewhere that is not filled with fuel where the gas collects before passing to the offtake. The gas is at a high temperature so that if air leaks into a suction producer at this point some of the gas will be burned. Joints in the producer shell at such a point may be made by covering a narrow strip of one of the surfaces that are to be joined with manganese-lead cement and laying dry asbestos rope on it. When two flanges that are bolted together are being joined by this kind of a joint, the asbestos rope may be kept in place by tying it to the bolts. The manganese-lead cement may be made by taking 1 part of red lead by volume, 1 part of white lead, 2 parts of black oxide of manganese and mixing them with boiled linseed oil to about the consistency of putty. This cement should not be used

when machined surfaces are being joined, as such a joint cannot be broken without injuring the finished surfaces. This joint is usually made to be permanent, so the asbestos rope is frequently protected from injury by filling the space between the flanges outside of the rope with neat cement. Neat cement is Portland cement wetted with water until a plaster of the required consistency is formed.

When a joint that is exposed to a high temperature must be made so that it can be readily taken down, a gasket of sheet asbestos from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch thick softened in water may be used. Such a joint as this is suitable for use in the piping between the producer and the scrubber.

34. Joints that must be tight against gas or suction pressure, but are not exposed to very high temperature, may be made as follows: When the joint is to be made permanently, dry asbestos rope may be used. After the joint is made up, the exposed surface of the rope is covered with manganese cement, which is allowed to set and the joint is finished with neat Portland cement. This joint is suitable for use in the wet scrubber.

In other cases, joints that must be gas-tight are arranged to be plugged, or calked, with asbestos rope. After the calking is done, the joint is sealed with a mixture of asbestos pulp and fireclay. This kind of joint is suitable for either a high or a low temperature when the joint is to be made up permanently.

Joints that are to be broken occasionally, may be made with dry asbestos rope, or if a tighter and more permanent joint is desired, the asbestos rope may be laid in manganese cement on one flange and the other flange covered with a mixture of graphite and machine oil to keep the rope from sticking. The first-mentioned of these joints is suitable for places in which a small amount of leakage will do no great harm, such as the flange of the charging hopper or poke holes of a down-draft producer. The other joint is used when the joint must be tight but the temperature is not high, as at the top of the wet scrubber.

35. Joints for doors and manhole covers that must be removed frequently may be made by cementing a $\frac{1}{16}$-inch asbestos gasket to one of the surfaces with white lead and coat-

ing the other surface of the joint with a mixture of graphite and machine oil. This joint cannot be exposed to a very high temperature as that would burn the machine oil.

Joints between pipe flanges may be made either with or without gaskets. When the flanges are rough and the temperature is not too high, a $\frac{1}{4}$-inch sheet-rubber gasket may be used. When the flange surfaces are machined smooth, a gasket need not be used but the flange surfaces should be covered with red or white lead.

Sometimes joints are made between surfaces where the leakage of gas is of little or no importance, the chief object being to provide a firm even bearing for one or the other of the joint surfaces. The joints between the brick lining and the mantel *h*, Fig. 11, and between the mantel and the columns *g* are in this class. The joint between the mantel and lining may be made by coating the mantel with a layer of asbestos pulp mixed with fireclay on which $\frac{1}{8}$-inch sheet asbestos is laid. The bearing for the mantel on the columns may be made by placing $\frac{1}{8}$-inch sheet asbestos softened in water on top of each column.

MANAGEMENT OF PRODUCERS

PREPARING PRODUCERS FOR OPERATION

36. Foundations for Producers.—The foundations for producers should be built in accordance with plans furnished by the makers. As a rule, it is necessary to set both the producer and the scrubber on slightly elevated platforms of brick or concrete, to raise the apparatus to a level where it will be easily accessible to the operator and to bring the various parts of the system in proper alinement, so that the pipes and fittings furnished by the maker will connect as intended. Special cases may occur where the conditions are such as to require some deviation from standard plans, and in such instances the manufacturer of the apparatus should be consulted and his recommendations and suggestions followed.

Upon the arrival of the machinery at the place where it is to be installed, it is well to examine all the parts for defects and to clean thoroughly all vessels, castings, tanks, etc., of any packing material, dirt, or sand left accidentally in the castings at the foundry. This suggestion applies to the various parts of the gas producer, as well as to the pipes and fittings.

LINING THE PRODUCER

37. Firebrick and Mortar.—Where the firebrick lining consists of special shapes, as is the case in most suction producers as well as in small sizes of pressure producers, the bricks should be carefully examined and any that are damaged, broken, or cracked, rejected. As a rule, a few extra bricks of each size are furnished, to allow for possible shortage of material that may be caused by the accidental breaking of some of the bricks while in transit.

Before attempting to place the lining in the producer shell, it is advisable to set the lining up on a floor or any other level place outside the shell, and to make sure that the various bricks fit without leaving excessively large spaces or crevices. If necessary, the bricks should be ground to each other, so as to remove any irregularities in shape and to reduce crevices to not more than $\frac{1}{16}$ inch at the joints. It is also necessary to see that the size of the lining is in accordance with the producer shell, that the circle formed by the bricks is approximately 1 inch inside of the shell, and that, when making proper allowance for mortar, the total height of the lining will be such as to bring it up to the desired level inside of the producer.

38. After the producer is leveled on its foundation, the brick lining may be laid. The mortar with which the bricks are laid should be made of fireclay that will withstand the action of the fire. It is desirable to make the mortar of the same clay as the bricks so that the bricks and the mortar will expand the same amount when the lining is heated. The mortar, made thin with water, like a thin mud, is commonly called *slurry*, and it should be so thin that it can be applied

with a brush like paint. Slurry must be thoroughly worked so that it will be smooth and of uniform consistency and contain no lumps. The bricks are dipped in this slurry and rubbed together until a tight joint is formed, and some of the slurry is poured into the joints at the ends of the bricks to make them tight.

39. Drying the Lining.—Before gas can be generated in a newly lined producer, the lining must be dried slowly. If the lining is dried too rapidly, it will crack or the daubing that was used to smooth the inside of the lining will peel off. The inside surface is thus left rough and the clinkers will adhere to it more firmly than they would to a smooth surface. The lining is dried by means of a wood fire that is kept burning for two or three days.

Any openings or fissures that show on the inner surface of the lining, and that are therefore exposed to the heat of the fire, must be filled with a smooth pulp made of fireclay, asbestos, and water, of about the consistency of ordinary putty. This pulp will withstand the action of the fire, while mortar made of fireclay and water alone would crumble and fall away in a short time. The pulp must be rammed tightly into all fissures, and the whole inside of the lining smoothed up if the irregular shape of the bricks requires it.

It is of the utmost importance to have the inner surface of the lining as smooth as possible, so as to prevent clinkers from adhering to the wall. It also prevents the poking tools from catching in the joints of the brickwork and damaging the lining, when trying to remove the clinkers.

40. Filling Between Lining and Shell.—The lining is usually insulated from the shell of the producer by having the space between the bricks and the metal filled with a suitable material. Sand has been used, and if of the proper grade it will answer the purpose very well. The best sand for this purpose is molders' sand that has been used in the foundry for making iron castings. A much better material, however, although slightly more expensive, is *mineral wool*. **Mineral wool** is made by subjecting molten slag to a strong air blast,

the cooled product having a porous, fluffy appearance resembling cotton. Sand has the disadvantage of being liable to run out of any cracks that accidentally develop in the brick lining. This of course would necessitate taking enough of the producer apart to permit replacing the sand lost in this way. Mineral wool will stay in place as long as the lining lasts, and the freedom from danger of a shut-down, such as might occur where sand is used, will more than pay for the additional first cost of the mineral wool. Another filling is made by mixing fireclay and sand half and half with just enough water so that it can be worked into place between the lining and the shell, or a mixture of fireclay and asbestos may be used.

41. Before filling the space between the lining and the shell, all the fissures around the fire-doors and the annular space around the bricks should be filled first, with a pulp made of fireclay, asbestos, and water, the same as that used for smoothing up the inner surface of the lining. Next the space should be filled with this pulp to a depth of several inches and then with mineral wool or other filling material up to within 2 or 3 inches of the top of the lining. The remainder of the space may then be filled with pulp like that used in the bottom. This makes the whole space tight against leakage and keeps the insulating material in place, as the pulp will become hard after the fire is started in the producer. When the mineral wool is put in, it should be rammed tight with a suitable tool as soon as a small quantity has been applied, and the placing and ramming should be continued until the desired space is filled, so as to form a homogeneous mass of insulating material. After the lining and filling are completed, the top of the producer may be put in place.

FILLING THE SCRUBBER

42. After the scrubber has been placed in position, leveled up, and properly alined with the producer, the coke that is generally used as a purifying agent should be placed in the scrubber. In doing this, care should be taken not to break or

grind the coke, and thus make dust and small pieces that will pack the coke tight and interfere with the flow of the gas through the scrubber. When the scrubber is to be entirely filled, the pieces of coke should be selected carefully as to size and the larger pieces placed in the bottom, the size gradually diminishing toward the top. The lower portion of the scrubber may contain pieces of about 4 inches in size, while nothing smaller than 1½ inches should be used at the top. To avoid breaking the coke in handling, it should be let down into the scrubber by means of a basket, a second rope being fastened to the bottom of the basket, so that it can be tilted and emptied when it has reached the bottom. Another equally good method is for a man to stand on a board in the bottom of the scrubber and distribute the coke after it has been lowered into it. The contents of the scrubber should reach up to within about 6 inches of the lower edge of the gas-outlet pipe connected at the top.

Any coke that may accidentally fall through the scrubber grate should be removed from the space below the grate before the scrubber doors are finally closed. If this is not attended to, some of the small particles of coke may be washed into the pipe connections and cause trouble by clogging them.

PIPE CONNECTIONS

43. In making the pipe connections between the various parts of the apparatus, sharp bends should always be avoided, as they produce unnecessary friction and thus retard the flow of the gas in the pipes. Retardation of the flow is especially objectionable in connection with suction gas producers, and it is of considerable importance to provide long-sweep elbows rather than the ordinary cast-iron fittings. As producer gas always contains some impurities before it passes through the scrubber, it becomes necessary to clean the connecting pipes and fittings regularly. After leaving the scrubber, the gas may still contain a small amount of dust or tarry matter that will accumulate in the pipe connections. To enable the pipes to be cleaned without taking them apart, the fittings should be

provided with handholes and removable covers, for the purpose of making their interiors accessible.

44. The valve in the draft pipe that branches off from the connection between the producer and scrubber is more likely to become clogged by impurities than any valve beyond the scrubber. This valve must therefore be arranged so that it can be easily taken apart to be cleaned and lubricated. It is desirable to provide a drip pipe and valve from above the flue valve, for draining any water that may collect in the smoke pipe either from the atmosphere or by condensation.

45. In order to have the smoke pipe constructed so as to give a good draft, which is essential in keeping the fire alive when the plant is shut down, it should be run in the shortest and most direct way possible. The general arrangement of the smoke pipe is of course governed by local conditions, but it should not have any sharp turns nor run horizontally for any great distance. If it is necessary to have a short length of horizontal pipe before the stack turns vertically, there should be a drain provided at the bottom of the elbow where the turn is made. The vertical length of the smoke pipe must be sufficient to insure a strong draft, and if there are any buildings in the vicinity the top of the pipe should be carried several feet above the highest building. If this is not done, the gases that will escape from the stack while the fire is being started might cause annoyance.

If the smoke pipe is led into an old chimney that has been used before, it should be carried up through the entire length until it reaches the open air. This is of special importance if any stoves are connected to the same chimney, because, if a fire were lighted in one of the stoves, gas issuing from the smoke pipe into the chimney might be ignited and result in an explosion.

TESTING FOR LEAKS

46. Whether the producer is of the pressure or of the suction type, it is equally important that the apparatus itself as well as all pipe connections be made absolutely tight. Neglect

in this respect would cause leakage of gas in the pressure producer and result in danger to the health and life of persons in the producer room. While this danger does not exist in the suction producer, owing to the fact that the pressure in this type of apparatus is always below that of the atmosphere, small leaks would cause air to be drawn into the apparatus from the outside and result in weakening the gas and in rendering it of such quality as to prevent good results from its use in the engine. If the leak were very serious, the gas would become so poor as to cut down the power considerably and eventually stop the engine.

47. Before attempting to make gas, all the joints and connections should be tested. A safe method of doing this is to generate pressure in the apparatus by closing the valves and operating the blower provided for reviving the fire. By attaching a small pressure gauge at a convenient point before the pressure is raised, and letting the apparatus stand for a while afterwards it can be determined whether there are any leaks. If the gauge shows a fall in pressure, it is necessary to investigate and locate the place at which the leak occurs. Each part of the apparatus can be shut off from the others, by means of the valves provided, and the point of leakage can thus be accurately determined. When the leak is located, it should be stopped.

The parts most likely to become leaky are the coal-charging device and the fire and ash doors. In handling the fuel and the ash, it is almost impossible to prevent impurities from settling upon the surfaces of the doors and charging apparatus. It is therefore advisable always to clean these surfaces after fuel has been admitted or ash or clinkers have been removed. Joints that are suspected of leaking may be tested with kerosene or soapsuds while the pressure is on; the presence of bubbles indicates a leak.

OPERATION OF SUCTION PRODUCERS

STARTING THE PRODUCER

48. After it has been ascertained that everything about the apparatus is in good working order in accordance with the directions, the producer is ready to be put in operation. To start the fire, the generator should be filled to a height of about 18 inches above the grate, with dry, non-resinous wood, or with charcoal. A small quantity of cotton waste soaked in oil and placed upon the grate under the wood will aid in starting the fire. If fat pine—sometimes called *pitch pine*, on account of the amount of pitch it contains—or a similar wood is used to ignite the coal, a smaller quantity will be sufficient. In case the wood contains much pitch, no gas should be permitted to pass into the scrubber until the wood has been entirely consumed.

49. Before lighting the fire, the evaporator should be filled, and a small amount of water be allowed to overflow into the ash-pit. The water-seal box should also be filled, and the water supply turned on in the scrubber as soon as the fire is started. The valve in the draft pipe must be opened and the top of the hopper closed before lighting the fire. After igniting the wood, the ash doors, fire-doors, and the pipe supplying moist air from the evaporator to the bottom of the producer must be closed. The connection between the blower and the producer is then opened, and the blower started, turning it either by hand or by power, as the case may be, until the wood is burning freely. Follow this by filling in about 8 to 12 inches of coal and continue blowing for a while until the fire is burning brightly. After this, the producer and hopper should be filled practically to the top with coal. Continue the operation of the blower until the gas at the test pipe between the producer and the scrubber burns steadily with a bright blue flame. Then close the communication between the blower and the producer, and quickly remove any ashes or clinkers that may have been

deposited upon the grate. While doing so, the fire-doors through which these ashes are removed should be kept open no longer than is absolutely necessary.

50. Now reestablish communication between the blower and the producer and again operate the blower for a short time until the gas, by burning steadily with a blue flame, proves that it is of the proper quality. As soon as this is the case, all the apparatus, including the pipe connections between the scrubber and the engine, should be filled with gas, thus replacing the air with which they were previously filled. This is accomplished by closing the draft valve and also the vent pipe that branches off from the gas-supply pipe near the engine. The vent pipe is provided for the purpose of making sure that the whole pipe system up to the engine is filled with gas of good quality.

It will generally require from 10 to 15 minutes from the time of starting the fire until all the apparatus is filled with gas. There should also be a test pipe provided in the gas-supply pipe near the throttle valve on the engine. As soon as a trial at this point shows the gas to be of good quality, the plant is ready for operation and the engine can be started in the usual way.

FIRING THE PRODUCER

51. In order to secure steady and efficient service of the plant, it is necessary for the operator to accustom himself to performing the series of operations carefully and always in the same regular rotation. Experience has shown that the following method of procedure gives the best results: If the fire requires looking after, the first thing to do is to fill in fresh fuel practically up to the top of the hopper, so as to replace any coal that has been consumed during the run. The second operation should be the poking from the top. This is done for the purpose of removing any clinkers that may have begun to adhere to the walls of the brick lining, and also for the purpose of preventing the formation of hollow spaces in the hot bed of fuel known as *bridging*.

52. The fire should be poked at regular intervals, as determined by the quality of the fuel used and the experience the operator may gain while running the producer under the conditions of load in each particular case. It will not do to neglect removing the clinkers, because, if they should be allowed to accumulate on the walls of the brick lining in any considerable quantity, it would be impossible to remove them while the apparatus is in operation, and consequently it would be necessary to shut down the plant temporarily and interrupt the service.

53. The third operation should be the removal of the ash from the ash-pit under the grate. This is generally done with a bent scraper. The fourth and last operation consists of poking and removing clinkers from the grate through the fire-doors. With a stationary grate, a bent poker is used for this purpose, after the clinkers have been loosened with a straight bar of suitable shape and length. This removal of clinkers through the fire-door should be done quickly, in order to prevent the entrance of an excessive amount of air into the producer. One door at a time should be opened just enough to permit of the removal of clinkers. The whole operation of removing clinkers from the grate should not require more than 20 to 30 seconds.

These operations apply, of course, only to stationary grates. In other producers the cleaning may have to be done in a different manner and the directions of the maker must be followed in all cases.

STOPPING THE PRODUCER PLANT

54. The engine is stopped as usual by simply closing the gas valve and disconnecting the battery. At the same time, in order to stop the producer plant in the proper manner, the valve in the purge pipe must be opened at once, so as to provide an escape for the gases that continue to form in the producer for a short time after the engine has been stopped. Next, the hopper of the producer should be filled with fuel and the valve in the draft pipe opened. As soon as this valve

is opened, the valve in the purge pipe near the engine can be closed. The water supply to the scrubber and producer should then be shut off and the valves adjusted that regulate the level of the water in the seal and water trap between the scrubber and the producer, so that the gas will be shut off from the scrubber. Experience will show just how far to open the air supply that regulates the draft necessary to keep the fire alive over night without unnecessary waste of fuel.

The ash and clinkers should be removed from the producer, and the fire and ash doors kept closed. Should it become necessary to remove large quantities of clinkers, it will be found easier to do this immediately after stopping the plant and while the fuel is still incandescent. It is best, in such cases, to draw the fire completely and to remove the clinkers from above after opening the cover of the hopper.

RESTARTING THE PRODUCER

55. To start the plant after it has been shut down over night, it is necessary only to remove from the grate any ash or clinkers that may be deposited during the night, and to operate the blower until the gas burns with a bright blue flame at the test tube between the scrubber and the engine. Then open the vent and the scrubber valves, see that the hopper is closed tightly, and start the engine in the usual way.

CLEANING THE PIPE CONNECTIONS

56. It is always advisable to attend to the cleaning of pipes and fittings in the day time, so that it will not be necessary to use a light, as a flame brought too close might ignite the gas. It is also advisable, as a matter of precaution, to have more than one person present while the cleaning is being done, so as to guard against accidents.

The building or room in which the producer is located should be well provided with ventilators, so that any escaping gas will be quickly carried away. The gas is very poisonous, and, if it accumulates, is liable to render the work-

men unconscious and may cause death. Hence special care should be taken to avoid breathing it. Under ordinary conditions it will be found sufficient to have the pipes examined and cleaned once in 3 months.

57. The contents of the scrubber may last for a year or more before they require renewing. If it becomes necessary to clean the scrubber, the whole producer plant must be shut down. The manholes of the scrubber should first be opened, so that any gas contained in the scrubber may escape. It may require an hour or more for the gas to stop, after which the coke may be removed. Any sediment that may accumulate in the bottom of the water-seal box, at the bottom of the scrubber, should be cleaned out at least once every other day.

OPERATION OF DOUBLE-ZONE PRODUCER

58. Starting the Producer.—The bottom of the producer is filled with ash to a point somewhat above the iron blast hood, or tuyère, *q*, Fig. 11, this ash sloping down to the level of the lower observation holes *m*, and the fire is built on this bed. The fire for drying the lining is fed through the door *r*, the lining inside of the door being omitted for that purpose.

When the producer lining is sufficiently dried, the lining inside of the firing door is bricked up and the door itself is closed and sealed. The wood fire is kept burning in the producer and, after the firing door is sealed, coke is introduced through the opening *e*. The draft pipe is opened and the valve controlling the supply of air to the lower part of the producer is open but the steam valve is closed. When the lower fire is well started, the producer is filled to within about 3½ feet of the top with coke. The kindling for the upper fire is then laid.

59. Before the fire is lighted, the valves must be set so that the gas from the producer goes out through the purge pipe instead of the draft pipe. The exhauster is started to produce the necessary draft and water is turned on at the sprays in the

wet scrubber. The valve controlling the supply of air to the upper fire is opened and the upper fire may be lighted. A quantity of oily waste is thrown in on top of the kindling and a piece is placed at the side of the opening *c*. When this piece has been lighted, it is pushed into the producer and the opening is closed as soon as the wood is ignited. The operator should stand well away from openings into the producer when the lighted waste is pushed in as there may be a flash of flame following the ignition of the waste in the producer.

Coke is charged at intervals for three or four hours or until the lining is well heated, after which time the charging of coal may be commenced gradually. A layer of coal 6 inches thick is spread next to the lining and the filling is continued toward the center until the whole fire is covered. A properly laid charge of coal will be thick around the edges, growing thinner toward the center, and the amount charged at one time will be about what the producer can gasify in an hour.

60. The draft is downwards through the part of the producer above the vaporizer *c*. Tar and other gases are driven from the coal in this part of the producer and are made into permanent gases as in the ordinary down-draft producer. The coke that remains after the tar and accompanying gases are driven off passes down through the producer to the lower fire where it is burned and producer gas is formed much the same as in an up-draft producer. A sufficient quantity of steam is admitted to the upper and the lower fires to prevent the generation of too high a temperature. A temperature higher than is necessary for the proper formation of producer gas is wasteful, because the gas at high temperature carries away a large amount of heat, which must be removed during the passage of the gas through the wet scrubber, and so is wasted. A high temperature in the producer also causes the formation of clinkers that adhere to and damage the producer lining and interfere with the formation of gas by forming channels through which the air passes instead of mixing with the fuel. Cooling the fire with steam not only prevents these difficulties, but it also adds valuable heating elements to the gas.

OPERATION OF PRESSURE PRODUCERS

61. The directions already given for the care of producers apply especially to suction producers, but they are almost equally applicable to pressure producers, especially in regard to the firebrick lining, pipe connections, etc. But the arrangement of the fuel bed is different in the pressure type from that used in the suction producer. Instead of having on top of the incandescent fuel a large amount of coal that is not burning, the height of the fuel bed is limited to from $2\frac{1}{2}$ to 3 feet above the ash when using anthracite, and from $3\frac{1}{2}$ to $4\frac{1}{4}$ feet when using bituminous coal. This will require a pressure for the air blast of from 3 to 4 inches of water.

If the blast is too strong or the coal too fine, the fuel will burn too fast near the walls, and it will be necessary either to reduce the blast or to use a coarser grade of coal. To keep the fuel bed reasonably solid and avoid the formation of bridges or honeycombing, a certain amount of poking, or barring, must be done, the frequency of which depends on the character of the fuel or the rate at which the producer is working. A little experience and careful observation will enable the operator to determine just how often the fire needs attention, so as to keep it in the best condition for steady service.

When stopping a pressure producer, no unburnt coal should be left on top of the fuel bed; the top layer should be incandescent. The blast should be decreased just before stopping, the poke-hole caps removed, and the escaping gas lighted at the open holes. Then the blast may be shut off entirely. Air will be drawn into the producer by the receding flame, so that the gas in the producer will burn quietly without any violent puff.

BLAST-FURNACE GAS FOR GAS ENGINES

QUALITY OF GAS FROM BLAST FURNACES

62. The gas formed in a blast furnace resembles producer gas, and it may, when properly cleaned, be used as an engine fuel. The blast furnace is used for producing pig iron from iron ores. It varies from 40 to 100 feet in height, and from 12 to 25 feet in diameter. The fuel used is coke, and a temperature sufficiently high to melt the ore is produced by an air blast having a pressure of from 5 to 15 pounds per square inch above that of the atmosphere. About 150,000 cubic feet of gas is formed per ton of pig iron produced. In order that the iron may not combine with oxygen passing through the furnace, the amount of air admitted is insufficient to complete the combustion of the fuel, and hence the gas passing out of the furnace contains a large amount of carbon monoxide. Blast-furnace gas, however, does not contain so much combustible matter as does producer gas, but it contains enough to furnish considerable power when used in gas engines of suitable design. The average composition of blast-furnace gas is about as follows:

Gas	Per Cent.
Carbon dioxide, CO_2	8
Carbon monoxide, CO	30
Hydrogen, H	2
Nitrogen, N	60
Total	100

There is usually present some hydrocarbon that affects these percentages to a slight extent. The thermal value of blast-furnace gas varies from about 90 to 100 British thermal units per cubic foot, depending on the percentage of carbon monoxide present. It has been found, in practice, that the gas

from the blast furnace will furnish about 50 horsepower continuously for each ton of pig iron produced in 24 hours.

63. One of the principal difficulties to be contended with in connection with the use of blast-furnace gas in gas engines is the large amount of gritty dust that the gas contains. This necessitates very careful and thorough cleaning of the gas before it is admitted to the engine cylinder. The gas should be as nearly free from solid matter as it is possible to make it by any cleaning method now in use. When the gas comes from the blast furnace, it usually contains from 4 to 7 grains, and may contain as much as 12 grains of dust per cubic foot; its temperature is also high, ranging from about 500° to 1,000° F. or more. The amount of dust contained has been reduced by some of the best modern cleaning processes to as low as .01 grain per cubic foot, and even less, which is said to be less than the dust contained in ordinary air.

When the gas from the blast furnace is not sufficiently cleaned before it goes into the gas engine, the dust collects in the cylinder and causes heating and perhaps cutting of the cylinder surfaces. Sometimes, the dust collects in the combustion chamber or valves, becomes incandescent from the heat of the explosions, and causes preignition.

64. To get the greatest efficiency from the combustion of the gas, it should be cool and dry as well as clean. The high temperature of the gas causes it to evaporate some of the water used in the cleaning process and to carry with it a large percentage of moisture. This moisture is detrimental to the combustion, but is a great aid in getting rid of the dust. Moist dust adheres more readily to any surface than does dry dust; but the moisture must be removed before the gas enters the engine. This is done by cooling the gas, thus causing the moisture to condense. As it condenses, it falls to the bottom of the apparatus, carrying with it a considerable amount of dust.

The gas is forced through the cleaning apparatus by some form of blower.

CLEANING BLAST-FURNACE GAS

65. The method of cleaning blast-furnace gas varies somewhat in different plants, but certain types of cleaning apparatus are quite generally used. The cleaning process is carried on in three stages: the dry-cleaning stage, the wet-scrubbing stage, and the rotary-scrubbing stage. The number of pieces of apparatus and their arrangement varies greatly in different plants. Some plants have several pieces in the dry-cleaning department while others have only one or two. The same is also true of the wet-scrubbing stage. The kind of cleaners used in these two stages differs greatly in various plants; in some plants, two or three cleaners of the same kind are used in one or both of these stages, and in other plants several different kinds of cleaners are placed in series. In the rotary-scrubbing stage, Theisen washers are almost universally used.

66. Dry-Cleaning Stage.—The simplest piece of apparatus used for dry-cleaning gas is called a *dust catcher.* It is a large cylindrical tank with a conical bottom. The gas enters at one side near the top of the cylindrical part and leaves at the center of the top through a pipe which reaches well down into the tank. While passing through the dust catcher, the velocity of the gas is greatly reduced and some of the dust is thus allowed to settle out and collect in the conical bottom of the catcher. Some of the dust is frequently picked up by the current of gas even after it has settled to the bottom of the catcher and the effectiveness of the catcher is thus greatly reduced. A number of attempts have been made to increase the effectiveness of the dust catcher by introducing various arrangements of baffles, and the result has been to increase greatly the percentage of dust that is removed.

67. One of the most successful of the improved dust catchers, called a *centrifugal dry gas cleaner,* is shown in Fig. 12. The cleaner consists of a shell *a* having a conical bottom *b* to catch and hold the dust. The outlet pipe *c* is extended to *d* inside of the shell and the inlet pipe *e* enters the shell off

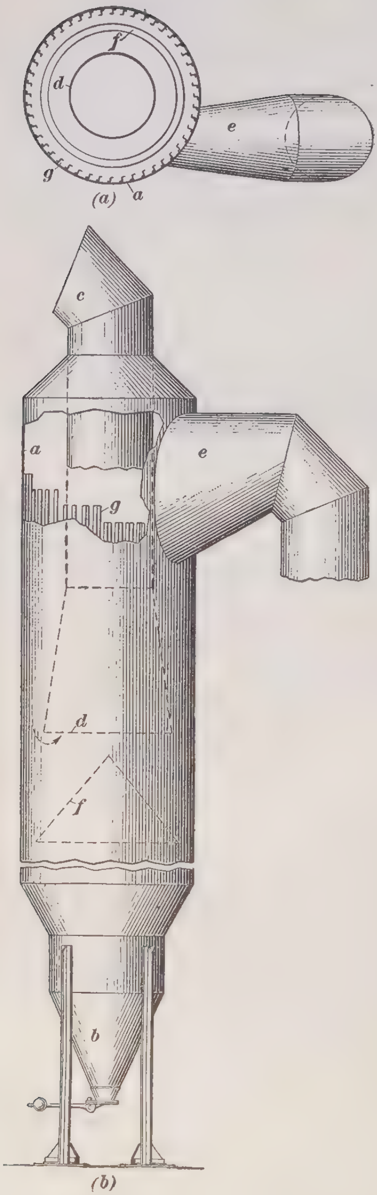

FIG. 12

center so that the gas has a circular motion around the inside pipe. The movement of the gas around the central tube causes the dust to be thrown out against the shell where it is caught behind the Z bars *g*. These bars are riveted to the shell across the path in which the gas is moving and prevent the dust from being carried through the catcher but permit it to slide down behind them into the hopper. The gas enters the central tube at *d* just above the cone *f* which keeps the current of gas from contact with the dust that has collected in the hopper. If the gas stream were permitted to strike into the hopper, much of the dust would be carried away and the effectiveness of the catchers would be correspondingly lessened. Two of these dust catchers are sometimes placed in series so that some of the dust that passes the first will be removed by the second. In other cases four dust catchers, two plain and two centrifugal, are placed in series.

68. Wet-Scrubbing Stage.—During the wet-scrubbing stage the gas may pass through only one or two

pieces of apparatus or it may pass successively through three or four different scrubbers. Water is, however, always used during this stage in the cleaning process. The *spray tower* used in this stage consists of a cylindrical tower with a device at the top to produce a shower of water all over the inside of the spray tower. The details of the spraying device vary somewhat in different towers, but the results are essentially the same with all of them. The gas enters near the bottom of the tower and passes up through the shower of water, which cools the gas and washes some of the dust out.

The *baffle washer* is little, if any, more complicated than a spray tower. It consists of a shell containing a series of baffles arranged so that the gas passing up through the washer must zigzag back and forth through a sheet of water. The dust is washed out of the gas by the water and is carried away by it. After wet dust is removed from the gas, it is not readily taken up again as is dry dust.

69. In the *impinging washer* the current of gas is made to strike down on the surface of a pool of water, which makes the gas return in a course at right angles to or parallel to its former course. The sudden change in the direction of the gas flow throws the dust into the water, which prevents the current of gas from carrying it on through the washer.

The *grid scrubber,* also called the *Zschoche scrubber* or *tower,* has a cylindrical shell and water spray very much like the coke scrubber, but instead of coke the tower is filled with wood or iron slats laid so that each layer is at right angles to the layer below. A sort of checker-work construction is thus formed through which the gas passes on its way through the scrubber. The gas enters the scrubber at the bottom and passes up through the grids, which are kept wet by the water from the spray at the top. When the gas comes into contact with a wet slat, the dust adheres to the wet surface and is washed down into the bottom of the scrubber tower. The coke scrubber can not be used for cleaning blast-furnace gas because the coke soon becomes clogged with the dust, thus requiring frequent shut-downs to clean and refill the scrubber.

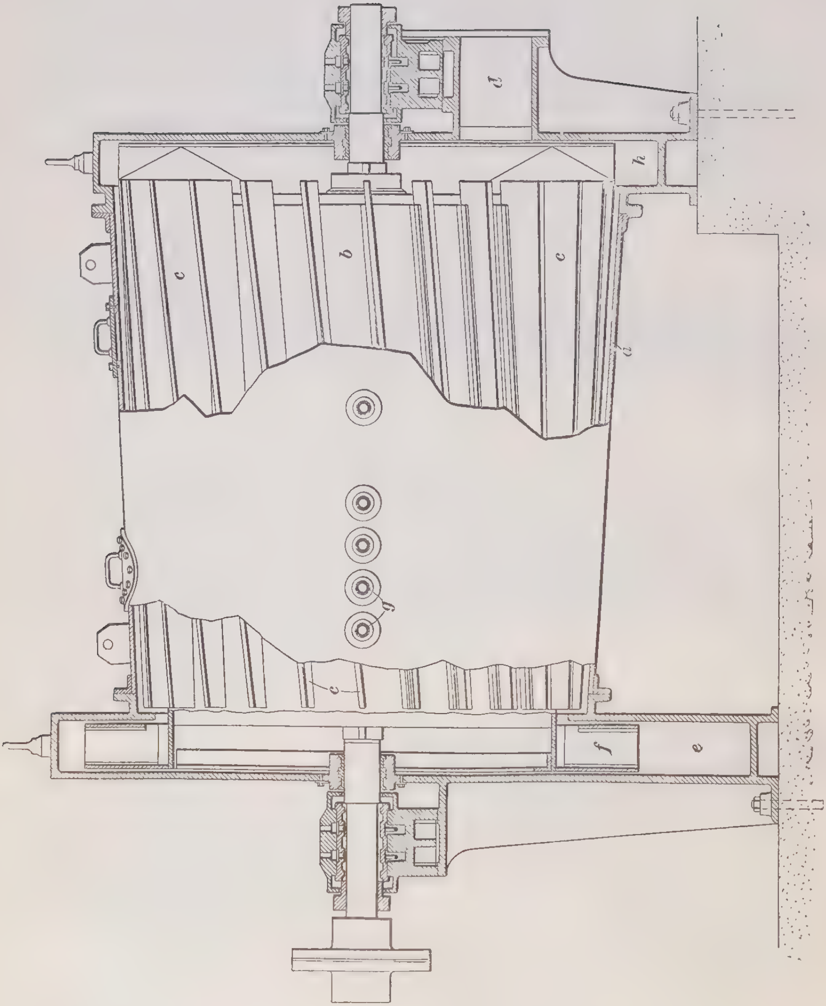

FIG. 13

70. Rotary-Scrubbing Stage.—The *Theisen washer* is almost universally used for the rotary-scrubbing stage in the United States. The gas enters this washer at one end and passes out at the other end while the water flows in the opposite direction through the washer. A rotating drum with vanes on its outer surface thoroughly mixes the water and the gas, and the dust is washed out with the waste water.

A Theisen washer is shown partly in section in Fig. 13. The shell *a* is conical and surrounds the drum *b* to which a number of vanes *c* are fastened. The gas enters at *d* and flows to the outlet at *e*. There is a series of fan blades at *f* forming an exhaust fan that draws the gas through the washer. The wash water enters at *g* and leaves the casing at *h*, thus flowing in the opposite direction to the current of gas. The vanes *c* extend diagonally across the face of the drum, each one forming part of a long spiral placed so that the rotation of the drum assists the flow of water toward the outlet. The water and dust, being heavier than gas, are forced out against the shell by the revolution of the drum, and the gas remains inside of the layer of water and dust thus formed. A large wet surface is provided in the Theisen washer by placing a wire screen inside of the shell so that the dust particles are thrown against or through it by the rotation of the drum. The dust adheres to the screen and shell and forms a mud that is washed away with the water and passes out of the washer.

71. When the temperature of the gas on leaving the blast furnace does not exceed 300° or 350° F., two Theisen washers placed in series have been found to clean the gas sufficiently to satisfy any but the most exacting conditions. In American practice, the temperature of the gas leaving the blast furnace is commonly from 500° to 700° F. The Theisen washer will not successfully clean such hot gas because the deposit of mud is baked on the screen and shell instead of being washed out by the water, and the gas is therefore cooled before being admitted to the Theisen washer. While the gas is being cooled, a considerable amount of dust is removed so that it is sometimes possible to dispense with the second rotary washer.

MANAGEMENT OF STATIONARY GAS ENGINES

INSTALLATION

SELECTION OF ENGINE

POINTS GOVERNING SELECTION

1. In selecting a stationary gas engine there are several important points to be considered, and the engine that embodies the greatest number of desirable qualities is the one to be preferred. First of all, the engine must possess sufficient capacity to accomplish the desired work. It must also be adapted to the requirements of speed, regulation, and direction of running imposed by the work to be done. It should be economical in fuel consumption, reliable in service, and of simple construction. The kind of fuel to be burned will depend largely on the location in which the engine will be used and may be either a liquid, such as crude oil or some of its distillates, or a gas, such as illuminating, producer, blast-furnace, or natural, gas.

2. Although a few manufacturers underrate their engines, that is, allow for a certain percentage of overload, the more general practice is to give an engine the highest rating possible, as this is a good selling point. Therefore, in determining the size of an engine for a given amount of work, it should be borne in mind that an engine that is called upon to run at its full capacity during the greater part of the time is actually

overtaxed. Working an engine to this extent will result in rapid wearing of the cylinder and piston, and consequent loss of power and economy due to leakage. When doing the maximum amount of work possible in a plant, the engine, if governed by the regulation of the number of impulses, should cut off at least once in four or five charging strokes. This will benefit the cylinder through the admission of charges of pure cool air at more or less regular intervals.

3. The type of engine decided on must be the one most suitable for the particular conditions under which the work must be performed. Engines for operating electric generators, especially for lighting purposes, must run with greater steadiness than is generally required for ordinary power. There are other cases—such as the operation of sensitive typesetting machines—where a very uniform speed is desirable. The question whether a horizontal or a vertical engine should be selected must be settled with a view to local conditions of available space and the character of the work to be done.

4. The consumption of fuel should always be in proportion to the work performed by the engine. The governor should respond promptly to any fluctuation in the load, and the friction loss should be kept at a minimum by proper methods of lubrication. The attainment of good results depends largely on careful workmanship, as well as on properly proportioned valves and liberal bearing surfaces.

5. The engine should be capable of being started promptly without great exertion, of developing its rated horsepower, and maintaining a steady speed, while consuming the normal amount of fuel.

6. Other things being equal, the engine that is simplest in construction and operation is to be preferred. This, however, should not be carried to a point where reliability of running and accessibility of the working parts are sacrificed. All the working parts, such as piston, connecting-rod, valve gear, ignition device, etc., should be easy of access for cleaning and necessary repairs.

EXAMINATION OF ENGINE

7. Even a casual inspection will reveal to the eye of a mechanic certain evidences of good or bad workmanship. Among the points that should be observed are the condition of the threads and the fitting of the nuts and their wrenches. Threads should be full and smooth, and the nuts should fit so as to enable them to be turned by hand on the studs or bolts, although they should fit snugly—that is, without play. The jaws of the wrenches should fit the nuts exactly. The fit of pins, levers, or links can be inspected by moving them by hand, and they should slide smoothly and evenly. Whenever possible, moving parts subject to wear should be properly hardened to a moderate depth below the outer surface. This refers especially to cams, rollers, blades, and pivot pins.

8. When the engine is in motion, good workmanship is indicated by smooth and noiseless running. There should be no pounding or clattering sound, which would indicate lost motion and loose-fitting bearings or piston. The flywheels should run true and without vibration. If the rim of the wheel should show any vibrating motion at the time of the explosion, it would be evidence of weakness either in the crank-shaft or in the wheel itself. The proper balance of the revolving and reciprocating parts is indicated by the absence of any forward and backward sliding of the engine bed on its base or foundation.

9. When the engine is operated with illuminating or other gas the consumption of fuel is best determined by reading the meter at the beginning and at the end of a certain period of time while the engine is running under its rated load. As a rule, manufacturers guarantee the power and the gas consumption per brake horsepower under full and partial loads. An engine using gasoline or other liquids should be tested as to its fuel consumption by connecting the pump to a graduated bottle of about 1 gallon capacity, and the amount used for a certain period should be noted. A good engine, running with ordinary gasoline, should use about a pint of fuel per brake horsepower per hour when running under its rated load.

10. Before deciding on the make and type of engine contemplated for a certain purpose, it will always pay to investigate the working of engines of the same manufacture that have been in use for a reasonable length of time. Reports from reliable users will go far toward determining the actual merits of an engine, its economy, the amount of repairs it may be expected to require, and other matters of vital interest to the power user.

ERECTING THE ENGINE

LOCATION OF ENGINE

11. The selection of the most suitable location for an engine deserves careful consideration. The space to be occupied by the engine should, if at all possible, be separated from the rest of the room by a partition. Sufficient space should be allowed around the engine, especially on the valve and governor side, where the space should be not less than 3 feet, to permit of easy access to any part of the engine. In all factories or shops where the presence of flying dust is unavoidable, it is necessary that the engine room should be surrounded with dust-proof walls. A room well lighted and ventilated is a great help in keeping the engine in proper condition, since it allows the attendant to watch closely the lubrication, valve motion, action of the governor, etc. The use of an open belt is always preferable to a crossed belt running from the engine to the line shaft. The engine should be set in relation to the direction in which the shafting or machines to be driven will revolve, and the question of open or crossed belt should be decided with this point in view. The distance between the centers of the engine shaft and the line shaft or the machine to be operated should never be less than 10 feet for engines up to 10 horsepower, and from 12 to 20 feet for engines of larger size.

FOUNDATIONS

12. When the engine is of the portable type it should be bolted firmly either to a rigidly constructed skid, or to a specially constructed framework and running gear. If the engine is to have a permanent location, as in a shop or power plant, it should be bolted firmly to a solid foundation built according to the size and design for that particular engine. It should be borne in mind that while the vibration of a horizontal engine is along the ground line, that of the vertical engine is perpendicular to the ground line, and that the vibration of the single-cylinder engine is much greater than that of the multicylinder engine.

13. Foundation Templet.—The location of the engine having been determined, the foundation may be prepared. Plans and specifications giving the size, depth, and material of the foundation are usually supplied by the builders of the engine, and in many cases a templet is also provided by them. This templet is a rigid framework, made of 1- or $1\frac{1}{4}$-inch boards from 4 to 6 inches wide, in which holes are bored corresponding to the holes in the engine bed through which the holding-down, or foundation, bolts must pass. If the templet is not provided by the maker of the engine, it should be carefully constructed in accordance with the dimensions given on the foundation drawing. If the engine bed is at hand, it is well to measure the distances between bolt holes, and compare these distances with those shown on the drawing. If they do not agree, as is sometimes the case, the holes in the templet should be located by measurements taken from the engine bed. The engine builders often furnish the foundation bolts, nuts, washers, and anchor plates.

The center lines of the cylinder and crank-shaft should be marked on the templet with a scriber. In setting the templet, care should be taken to have it the required height from the floor, level on top, and square with the building. This is done because the templet is used to determine the height of the top of the foundation bolts as well as their position laterally. If

the shafting to be driven is in place, the center line of the crank-shaft as marked on the templet must be brought parallel with that of the line shaft. To accomplish this, drop two strings *a*, Fig. 1, with weights attached, one on each side of the foundation *b*, and several feet away from it, from the line shaft *c* to the floor. Then set the templet *d* so that a string *e* drawn across it, and exactly in line with the center line of the crank-shaft, is at the same distance *f* from the two plumb-lines *a* suspended from the line shaft. The crank-shaft will

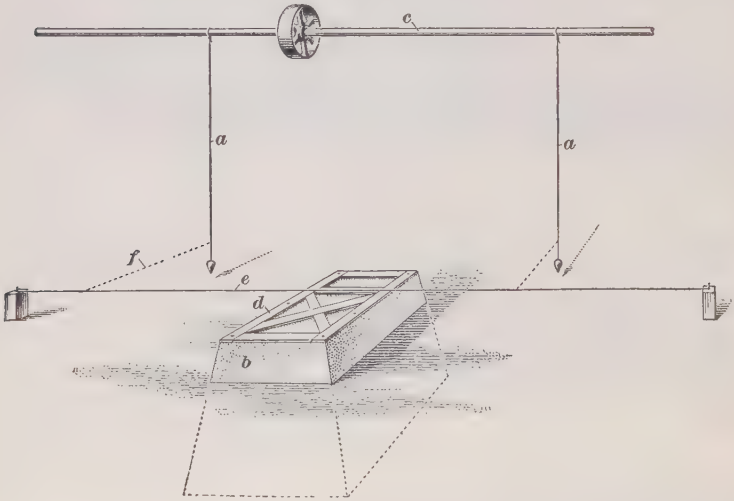

FIG.

then be parallel with the line shaft, so that they may be connected by pulleys and belt.

14. Placing Foundation Bolts.—After the templet has been set and securely propped up and fixed in position, the foundation bolts should be inserted, the top ends being allowed to extend the proper distance above the bottom of the templet. When the nuts and washers are in place, the ends of the bolts should project slightly beyond the nuts. The distance of the ends of the bolts above the bottom of the templet should be adjusted so that it will equal the distance that the bolts should project above the top of the foundation. The templet should

be carefully leveled when it is set, in order that these distances shall be correct.

In order to guard against any slight shifting of the foundation bolts while the masonry is being put in place, or against discrepancies between the foundation plan and the engine bed, it is advisable to surround the bolts with wooden casings or, preferably, with iron pipes about 1 inch larger on the inside than the diameter of the bolts. This will permit the bolts to be moved slightly in the foundation and their location to be adjusted to suit the actual measurements of the engine bed. These boxes, or pipes, will later be filled with grouting to give them a permanent position and prevent the engine from shifting on the foundation.

15. Building the Foundation.—The building of the foundation may next be undertaken. If brick is used, it should be of the hard-burnt quality, and should be laid in mortar made from a good quality of Portland cement and clean, sharp building sand, with a sufficient amount of water to render the mortar of the proper consistency. Common brick or building stone may be used for the inside of the foundation, but the outside should be faced with pressed brick.

In many cases, a foundation of concrete is cheaper or more convenient to construct than one of brick or stone, and, if built of a proper grade of material, is preferable to a brick foundation. A good mixture of concrete may be made of five parts, by volume, of broken stone, about $1\frac{1}{2}$ inches in size, two parts of clean, sharp sand, and one part of Portland cement, adding water in proper quantity and thoroughly mixing the material to give it the required consistency. After the pit has been filled with concrete up to the floor level, build or place a box under the templet, the inside measurements of which should correspond with the size of the part of the foundation that projects above the floor. Fill the box with concrete, and do not remove it until the mixture has become well hardened, which generally requires from 3 to 4 days. After the box has been removed, the sides and top of the foundation should be finished with cement mortar, so as to give it a smooth appear-

ance. The templet should not be removed until the foundation has completely hardened, as there is danger of the bolts being drawn out of their proper position during the hardening of the foundation.

16. A properly built concrete foundation becomes as hard as a solid mass of stone. Brick foundations for large engines should, if possible, be topped with a cap of limestone, or similar close-grained material. Oil has a deteriorating effect on brick foundations. In order to protect them against the injurious action of any lubricating oil that may accumulate on top, it is well to provide a sheet-metal oil pan in which to place the engine bed, or to have 3-inch plank covered with sheet metal to form the top of the foundation for engines of small or medium size.

The depth of the foundation required depends on the nature of the soil, and the pit in which the foundation is to be built should be dug down to solid earth. The distance it is necessary to dig in order to reach solid earth determines the length of the foundation bolts. They should extend to within 6 to 12 inches of the bottom of the pit. The anchor plates, which are attached to the lower ends of the bolts, should be of ample size, so as to prevent any yielding of the foundation material when the bolts are tightened.

17. The size and shape of the foundation will depend largely on the nature of the ground on which it is to be built. In a loose, sandy soil the engine will depend entirely on the dimensions and form of the foundation for steadiness; whereas, if the ground consists of hard earth or rock, the foundation need not be large, as the engine can be anchored to the rock. As the dimensions are governed by local conditions, no rules can be given for the size and shape of foundations to fit all requirements. Usually, the builders of engines have adopted certain foundation dimensions for average conditions, and these are given in catalogs or books of instructions. The following approximate proportions are, however, suggested for average conditions: For a horizontal engine, the length of the foundation should be from $1\frac{1}{2}$ to 2 times the length of the

engine base and the width from $1\frac{1}{4}$ to $1\frac{3}{4}$ times the width of the engine base, these dimensions being taken at the bottom of the foundation. The depth of the foundation may be from $\frac{1}{2}$ to $\frac{3}{4}$ times the length. The sides and ends of the foundation may be vertical, but it is more common to slant them inwards toward the top, so that at the top the foundation will be from 3 to 6 inches larger than the engine base all around. For vertical engines the length of the foundation should be about $1\frac{3}{4}$ times the length of the engine bed, measured at right angles to the shaft, and the width of the foundation should be $1\frac{1}{2}$ times that of the engine bed, measured parallel to the shaft. This applies even if the engine has more than one cylinder. The foundation must always reach a firm footing. If this should involve excessive depth, piles must be driven or the location of the engine must be changed. In ordinary soil the depth of the foundation of small or medium-sized engines is generally about equal to its length.

18. Preventing Vibration.—To prevent the vibrations caused by the explosions in the engine cylinder from being communicated to the building, the engine foundation should be kept free from contact with the foundation walls of the building. This is of special importance in office buildings, stores, etc. In cases where such vibrations are very objectionable, it is advisable to take the precaution of placing the foundation on a cushion formed by a 6-inch layer of mineral wool, tan bark, or some other insulating material. This should be placed not only beneath, but also all around the sides of the underground portion of the foundation. Cushioning the foundation in this manner not only prevents the transmission of vibration, but also prevents the noise caused by the running of the engine from being communicated to the rest of the building. A large and heavy foundation also tends to prevent the transmission of vibration, and when the engine is securely bolted to such a foundation most of the vibration will be absorbed by the foundation.

19. Timber Foundations.—In localities where brick, concrete, or stone foundations are not to be had, timbers may

be used. They should be of such length as to project several feet on each side of the engine bed. If several timbers are required to make up the desired height or width of the foundation, they should be bolted together in a substantial manner. The bolts that hold the engine to the timbers should extend through the entire depth of the timbers and be provided with large square heads fitted in countersinks of corresponding size to keep the bolts from turning when the nuts are tightened.

20. Support of Engines on Floors.—Engines of small or medium size are frequently set on upper floors, where a brick or concrete foundation is out of the question. In such cases, the engine is usually provided with a heavy cast-iron base of sufficient height to allow the flywheels to clear the floor; the heavy base absorbs a considerable portion of the vibration, and in a measure takes the place of a foundation. When located on an upper floor, the engine should be set in a corner near the walls, to avoid springing the joists. In every such case, the floor boards should be removed and a thorough inspection of the condition of the joists made, so as to be sure that they are of ample strength to sustain the weight of the engine and absorb the shocks caused by the explosions. Preferably, the engine should be placed so that the length of the bed extends across the joists. In order to take in as many joists as possible, 3-inch planks or heavier timbers projecting several feet on each side of the bed should be placed under it, and held to the joists by bolts extending through and secured by anchor plates underneath. The engine should be fastened to the plank by bolts in the same manner as in the case of the timber foundations.

21. Placing Engine Bed on Foundation.—After the engine bed has been brought alongside the foundation, the templet is removed and blocks are placed on top of the masonry high enough to clear the tops of the foundation bolts. The bed is then moved and set upon the blocks and gradually let down by inserting planks and removing the thicker blocks. Great care must be taken, in lowering the engine bed, not to mar the threads on the foundation bolts. After the bolts have been started in the bolt holes of the engine bed, a grouting of

cement and water should be poured into the spaces left around the bolts; the engine bed may then be lowered until its rests upon the foundation. Generally the bottom of the bed is planed smooth, so that, if the top of the foundation is level and smooth, the bed will rest firmly on the foundation. Any unevenness in the surfaces of the foundation or of the base of the bed must be taken up by wooden or iron wedges, which are inserted and adjusted until a spirit level applied to the engine indicates that it stands perfectly level. After the engine is leveled up, the nuts of the foundation bolts should be tightened gradually and evenly without straining the engine bed. If tightened carelessly, the bearings of the engine in the bed may easily be drawn out of line and cause serious trouble from hot boxes as soon as the engine is started.

22. Grouting.—After the bolts are tightened moderately, the space between the bedplate and the foundation is filled with grouting. The grouting may be made of iron borings mixed with cement, sal ammoniac, sulphur, and water in about the following proportions: two parts of sal ammoniac, one part of sulphur, five parts of cement, and forty parts of iron borings mixed with enough water to make a heavy paste. This mixture rusts firmly into place. A joint made of a rusting mixture is generally called a **rust joint.** Sometimes, melted sulphur alone is used, but one of the best groutings and the most easily applied is pure Portland cement mixed with water. The rust joint must be well tamped into place, while the sulphur and cement will flow in, suitable dams being constructed to hold it in its proper place. Bolt holes should also be filled with liquid grouting. Some builders, who use hollow bedplates of box form, fill the entire bedplate with concrete, to give it solidity and to reduce the tendency to excessive vibration from the knocking caused by loose bearings.

PIPING SYSTEM

23. Arrangement and Sizes of Piping.—It is customary for the engine manufacturer to supply a general piping plan, giving a diagram of the various pipes and their sizes, for

the fuel supply, the water inlet and overflow, and the exhaust pipes. The general scheme of these connections for gas and exhaust piping, subject to changes according to local circumstances, is shown in Fig. 2. The gas enters through the pipe *a*, and flows through the valve *b* to the gas bag *c*. From *c*, it passes through the pipe *d* to the engine cylinder *e*. The exhaust gases pass from the cylinder through the pipe *f* to the muffler *g*, and thence out of the pipe *h* to the atmosphere. The gas bag is furnished with the engine, and serves as a reservoir, which is necessary because the charges are taken into the engine suddenly and at intervals. During the suction stroke the gas bag will slightly collapse, and if the pressure should accidentally fall below the normal, the collapsing of the bag may partly close the gas pipe entering it. To guard against this, the pipes should extend well into the bag, that is, from 6 to 12 inches, according to the size. To prevent absolutely such interference with the supply, the pipe may run through the entire length of the bag, the gas entering through a series of holes drilled in the pipe. About twenty holes, varying in size

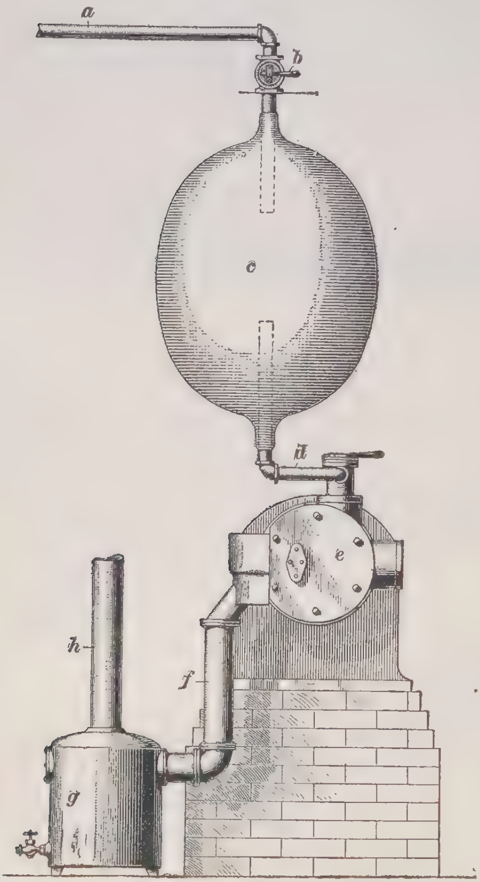

FIG. 2

from $\frac{1}{4}$ to 1 inch in diameter, according to the size of the engine and supply pipe, will be sufficient.

24. To obtain the full power that the engine is capable of developing when using illuminating gas, the size of the gas-supply pipe must be ample to permit the gas to flow without reduction of pressure, and will depend on the distance between the engine and the street main. Table I gives a safe estimate for the sizes of pipe to be used at different distances from the engine for light pressures of from $1\frac{1}{2}$ to 2 ounces. It should be borne in mind that the sizes given are the standard inside diameters, while in practice, especially with the smaller pipes, the inside diameter of an iron pipe is considerably oversize.

TABLE I

SIZES OF GAS PIPING FOR GAS ENGINE

Horsepower of Engine	Diameter of Pipe, in Inches		
	Within 15 Feet of Engine	Farther Distance of 90 Feet	Farther Connection to Main
2	3/4	1	1 1/4
3 to 5	3/4	1 1/4	1 1/2
6 to 10	1	1 1/2	2
11 to 18	1	2	2 1/2
19 to 28	1 1/4	2 1/2	3
29 to 45	1 1/2	3	3 1/2
46 to 65	2 1/2	3 1/2	4
66 to 100	3	4	5

25. Pressure Regulator.—In cases where the fluctuations in the gas pressure must be considered, and where the surrounding gas lights would flicker owing to the intermittent drawing of gas from the main during the working of the engine, a pressure regulator should be installed. One form of regulator is shown in Fig. 3. It consists of a balanced valve *a*, the stem of which is connected to a diaphragm *b*, and a helical spring *c*, the tension of the latter being adjustable. The gas enters at *d* and leaves at *e*, the diaphragm *b* being therefore

subjected to the pressure on the outlet side of the valve. If this pressure increases, the diaphragm is forced downwards, and the valve is closed to a greater or less extent, thus throttling the gas supply and lowering the pressure on the outlet side. By adjusting the spring *c*, any desired pressure may be constantly maintained at *e* regardless of variations in the pressure on the inlet side.

26. The pressure regulator must be placed in the supply pipe, so that the gas will pass through the valve before it reaches the rubber gas bag *c*, Fig. 2. A valve, shown at *b*

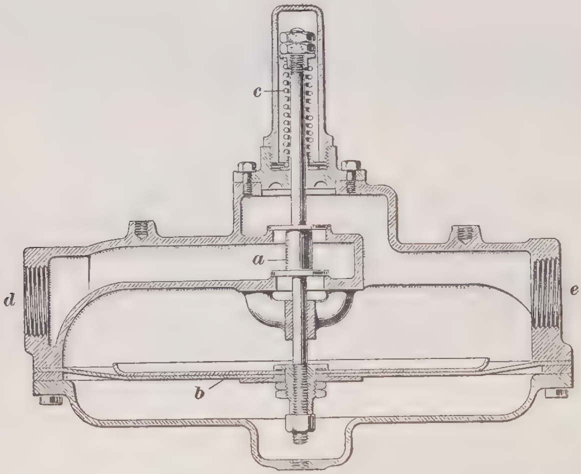

Fig. 3

should be placed in the supply pipe, so as to shut off the gas before it reaches the bag *c*, and should be within easy reach, to be opened or closed when starting or stopping the engine. As oil has a damaging effect on rubber, the bag should be enclosed in a suitable box or cover, in order to protect it from lubricating oil that might be thrown upon it by the revolving parts of the engine.

27. Gas Meter.—To permit a strict account of the gas consumption of the engine to be kept, a meter registering the amount of gas used by the engine should be installed. The meter should be placed as near as possible to the engine. The

following capacities of meters may be considered ample for engines of various sizes working under normal conditions, the meters being rated according to the number of lights they will supply.

TABLE II

SIZES OF GAS METERS

Horsepower	Size of Meter, in Rated Number of Lights	Horsepower	Size of Meter, in Rated Number of Lights
2	10	26 to 35	80
3 to 5	20	36 to 45	100
6 to 10	30	46 to 55	200
11 to 18	45	56 to 70	250
19 to 25	60	71 to 85	300

28. Piping for Natural Gas.—The pipe connections for natural gas are essentially the same as for illuminating gas. As a rule, natural gas is supplied at a higher pressure, which must be reduced by a suitable regulator to about 2 to 4 ounces before it reaches the reservoir near the engine. Owing to its greater heating value, a smaller amount of natural than of illuminating gas is required for developing the same power, the proportion being about 75 or 80 per cent. The size of the supply pipe near the engine may therefore be proportionately smaller for natural gas than the sizes given in Table I for illuminating gas.

29. Exhaust Piping.—The object of the exhaust pipe is to carry the waste gases or products of combustion into the open air. To do this effectively and with the least resistance or back pressure, the pipe should be of ample size and should run as straight as possible, avoiding any sharp bends. As the gases leave the cylinder at considerable pressure, the exhaust is noisy unless provision is made for muffling the sound. This is usually accomplished by placing a muffler in the exhaust pipe line near the engine, as shown at *g*, Fig. 2. A flange union should be provided between the exhaust pipe and the

engine, and between the exhaust pipe and the muffler, to facilitate the disconnecting of the pipe in case the exhaust valve or the cylinder head needs cleaning or repairing.

30. In placing the muffler and connecting it to the exhaust outlet of the engine, care should be taken to give the pipe a certain amount of flexibility, as a rigid arrangement would strain the exhaust-valve casing, owing to the expansion of the pipe when it becomes hot. This would result in rendering any packing between the cylinder and exhaust-valve casing leaky, an annoyance that can easily be avoided by a judicious arrangement of the muffler and pipe connections. The most efficient way to avoid this difficulty is to use an expansion joint, one form of which is shown in Fig. 4. The end *a* of the pipe leading from the engine is free to move longitudinally in the fitting *b*, which is screwed tightly on the pipe *c* leading to the muffler. The nut *d*, when screwed down, compresses the packing *e* and prevents leakage between the pipe *a* and the fitting *b*.

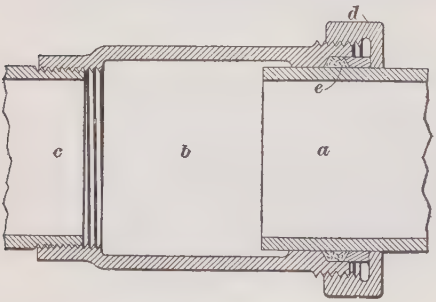

FIG. 4

The expansion joint is thus a simple form of stuffingbox, the packing being of asbestos wick thoroughly lubricated with graphite. Expansion and contraction due to changes of temperature cause the pipe *a* to move in and out of the fitting *b* without straining the pipe connections. The pipe from the muffler to the open air should never be smaller than the outlet on the engine. If a long pipe with several bends is unavoidable, the size of the pipe should be correspondingly enlarged.

31. To avoid causing annoyance, from the exhaust gas, to people in neighboring buildings, the exhaust pipe should be carried above the roof of the building. If this is done by way of a convenient flue or chimney, the pipe should be carried up through the entire length of the flue. If the pipe terminates

inside of the flue, there is danger of unburned gases accumulating in the flue and doing serious damage when fired by the first hot exhaust issuing from the pipe. As the exhaust gases cool during their passage through the pipe, a certain amount of water collects in the pipe due to the condensation of the water vapor in the exhaust gases. To permit the exhaust connections to be drained, all vertical exhaust pipes should be fitted with a **T** at the bottom, one opening of the **T** being provided with a plug or drain cock.

32. In densely populated or crowded residence districts, where even the muffled sound of the exhaust might become objectionable, the noise can be entirely eliminated by injecting a very small stream of water into the exhaust pipe. A portion of the overflow from the water-jacket may be used for this purpose. The connection should be made about 4 to 6 inches below the exhaust outlet on the engine, to guard against any water coming in contact with the exhaust valve and seat. A $\frac{1}{8}$-inch pipe will supply enough water to deaden effectually the noise from the exhaust of a 20-horsepower engine. The water has the effect of cooling and decreasing the volume of the hot exhaust gases, and the greater portion of the water is carried away with the gases in the form of steam. A drain connection must be provided at the lowest point of the exhaust pipe, and this must be kept open constantly, to permit any surplus water to run off to the drain pipe or sewer.

33. In running the exhaust pipe through wooden floors or partitions, metal plates should be used around the pipe, allowing 3 or 4 inches clearance between the pipe and the floor to protect the woodwork from danger of fire. For the same reason, the exhaust pipe, if placed on a wooden floor, should rest on bricks or similar material. If the exhaust outlet ends in a vertical pipe, it is advisable to place an elbow at the top end, to prevent water or solid obstacles from getting into the pipe.

34. Piping for Gasoline.—The gasoline storage tank should be located according to the regulations laid down by the

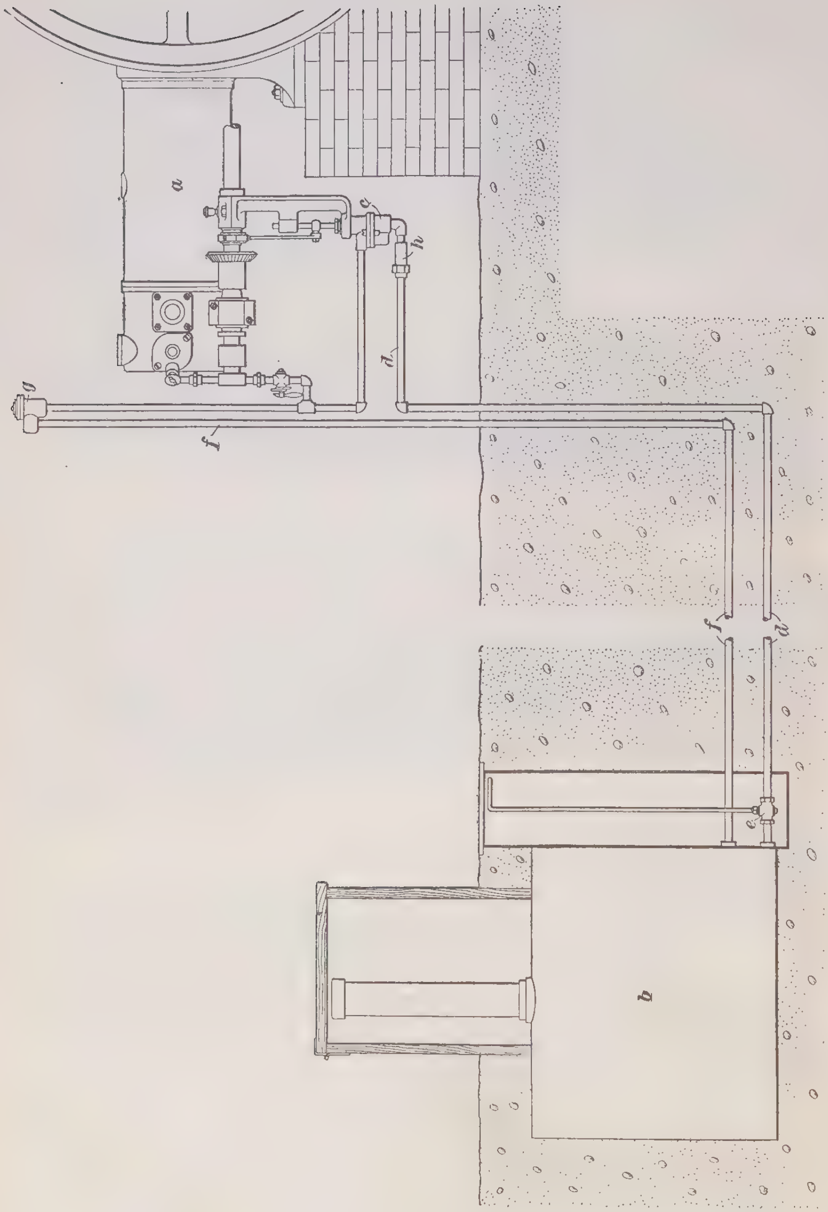

FIG. 5

National Board of Fire Underwriters. Considerations of safety require that the tank be placed below the level of the engine-room floor, making it impossible for the gasoline to flow to the engine by gravity. Such an arrangement is shown in Fig. 5, with the engine at *a*, the gasoline tank at *b*, and the pump at *c*. The tank *b* should be so placed that the bottom of the tank will not be more than 5 feet below the level of the pump *c*, as, owing to the nature of gasoline, it cannot well be raised through a greater height even with a well-constructed pump. The supply pipe *d* is attached at the bottom of the tank, and should have a constant rise toward the engine. The tank is placed preferably in a brick-lined vault, large enough to allow access to the valve *e* or other valves in pipes near the tank. The overflow pipe *f*, through which the gasoline returns from the cup *g* to the tank, enters the tank above the supply pipe *d*. A drain cock must be placed at the lowest point of the tank, to allow any water that may accumulate there to be drained off. Moreover, the gasoline may contain a little water, which, being heavier, will settle to the bottom of the tank, and in time will increase in quantity to such an extent as to be drawn into the engine and cause it to stop.

35. Stop-cocks should be provided in both supply and overflow pipes near the tank. They may be closed, so as to allow the pipes and connections to be examined without having to empty the reservoir. A stop-cock in the supply pipe, to be closed when the engine is shut down overnight, has the additional advantage of keeping the pipe filled with fuel and obviating the necessity of having to pump it up by hand before starting the engine in the morning. It is very important to have all joints in the gasoline pipes perfectly tight. Galvanized pipe and fittings should be used and all screwed joints soldered. Before the pipes are put in place, they should be thoroughly cleansed of any impurities by washing with kerosene. All pipes and fittings should be carefully examined to make sure that they show no defects, such as imperfect seams or blow-holes, that would admit air into the pipe and prevent the pump from lifting the gasoline.

36. In the smaller engines burning liquid fuel, especially those of the portable type, a small fuel-supply tank may be mounted on the engine bed or frame at such a height that the fuel will flow to the mixing chamber, or carbureter, by gravity. In some cases the builders prefer to place this tank in the engine bed, in which case the liquid must be pumped to the mixing chamber. The second method gives a more compact and neater looking engine than the first, but has the disadvantage of requiring a pump.

37. A filter, shown at *h*, Fig. 5, is usually furnished with the engine; it should be placed in the supply pipe before the point where this pipe enters the pump. Neglect in supplying a filter may result in impurities being washed out of the pipe, settling under the pump valves, and interfering with the action of the pump. In case no filter is supplied by the maker of the

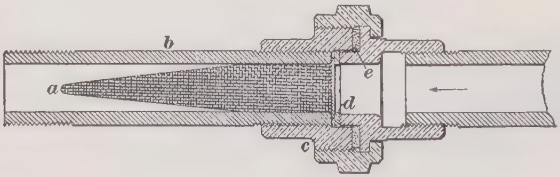

Fig. 6

engine, it is well to provide one. In Fig. 6 is shown a good form of filter, which is made of fine-wire gauze *a* inserted in a short nipple *b* and held in place by a standard brass union *c*, the gasoline passing through in the direction of the arrow. The gauze is held in place by a brass ring *d*, and the joint is made tight by a leather washer *e*. In running the gasoline pipe to the engine, care should be taken to keep it away from the exhaust pipe, as the heat from this pipe would interfere with the flow of gasoline by producing a quantity of gas in the pipe that would prevent the liquid from being pumped up into the engine. Gasoline pipes that are placed under ground should not be covered with earth until a test has proved that they are perfectly tight. It is well to make sure of this by starting up the engine, keeping it running for a day or two with the pipes exposed, and watching for leaks. To facilitate taking down

any pipe connections near the engine or disconnecting the tank, use brass unions in the gasoline pipes near the pump and the tank.

COOLING SYSTEM

38. Temperature of Cooling Water.—In a well-constructed gas engine having ample cooling-water space around the cylinder and valve casing, the water supply should be so regulated as to maintain a temperature of about 160° to 180° F. This temperature will prevent excessive heating, which would interfere with the proper lubrication of the piston and cylinder and with the easy operation of the valves and igniter, as well as destroy the packings between the cylinder and the valve casings, where such packings are employed.

Keeping the temperature of the cooling water much below 160° F. would have an injurious effect on the condition of the piston and cylinder, and prevent getting the best results from the engine, even with a proper combustion of the mixture in the cylinder. If the water when it leaves the cylinder is practically cold, the cylinder will be cooled to such an extent as to cause condensation of the exhaust gases, resulting in corrosion, undue wear of the piston, and sticking of the piston rings, and a large amount of heat that should be utilized in doing work will be carried away by the water. At full load the cooling water carries off about $1\frac{1}{2}$ times the heat absorbed in power delivery.

39. Tank System of Cooling.—For engines of small or medium size, cooling by means of a water tank, as shown in Fig. 7, is most efficient and least expensive. When employing a tank of proper size, the question of keeping the water at the proper temperature is easily solved. The amount of water that must be added in this system of cooling is limited to the small quantity that is lost by evaporation. The essential points to be observed in making connections between the engine and the tank are as follows: The tank must be of such shape that the opening for the pipe *a* at the top is at least 3 feet above the top of the engine cylinder *b*. The pipe must be of ample size,

so as to afford little obstruction to the circulation of the water. The water should be taken from a convenient point immediately above the bottom of the tank, and should enter the cylinder jacket at the bottom and leave at the top. The level of the water in the tank should always be several inches above the entrance of the water pipe *a* near the top of the tank. A drain

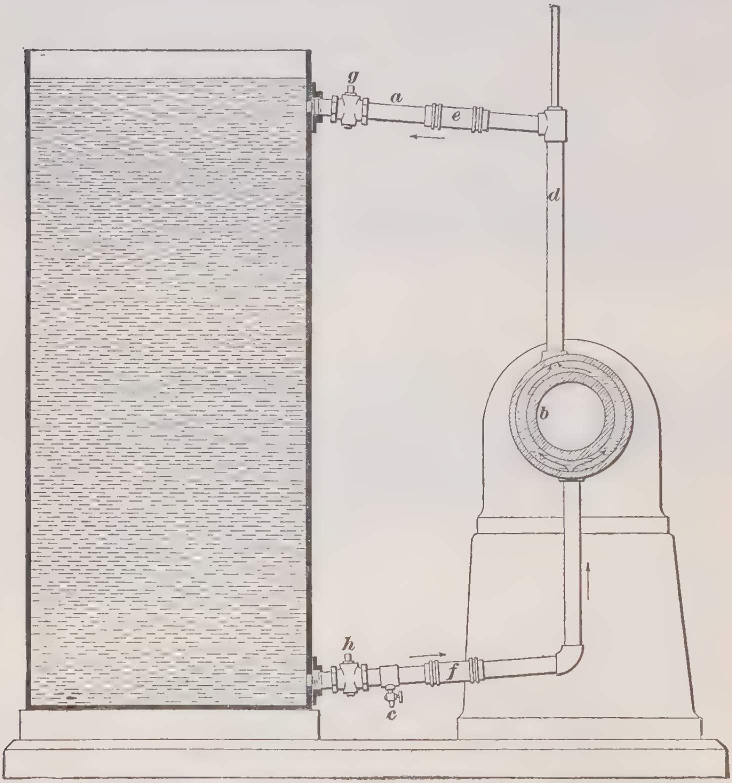

Fig. 7

cock *c* should be placed at the lowest point of the pipe, to allow the water to be drawn off in cold weather, and thus prevent freezing and consequent bursting of the water-jacket. The vertical pipe *d* from the jacket to the tank should be extended from 6 to 12 inches above the water level in the tank, as shown, to allow for the escape of air and to facilitate the circulation.

Where the engine is not placed on a rigid foundation, short pieces of rubber hose *e*, *f* should be inserted in the horizontal pipes at top and bottom, so as to prevent the communication of any vibration from the engine to the tank. The valves *g* and *h* permit the tank to be shut off when the cylinder jacket must be drained.

40. The capacity of the cooling-water tank for an engine running under an approximately full load may safely be put at 50 gallons per horsepower. For large engines, above 20 horsepower, the tank system of cooling may be successfully employed, if supplemented by a circulating-water pump driven

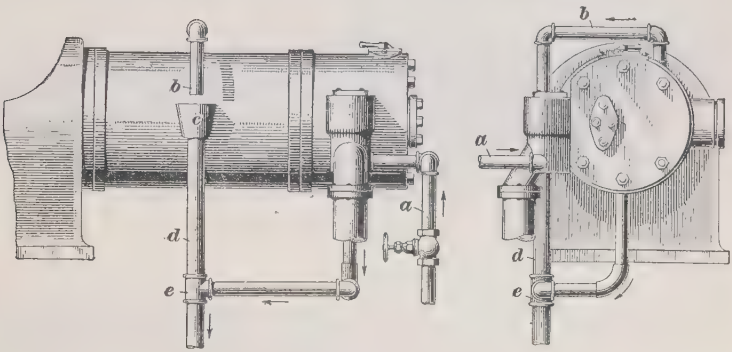

Fig. 8

from the engine or any part of the line shaft. The pump must be so set and connected as to take water from the bottom of the tank or cistern, force it through the jacket, and return it to the tank. If the cistern or tank capacity is limited, which is likely to be the case in large installations, the use of suitably constructed air-cooling arrangements is necessary. These arrangements generally consist of a series of slanting surfaces, one below the other; the water, after passing through the engine, is delivered by the pump to the top of the cooler, and descends by gravity, flowing over the surfaces and being cooled by contact with the air, before it returns to the tank or cistern. The capacity of the water-circulating pump should be about 15 gallons per horsepower per hour.

41. Cooling by Steady Water Supply.—Where a steady supply of cold water from water mains or any other source is convenient and inexpensive, the supply pipe can be of smaller size than when using the tank or circulating system of cooling. A $\frac{1}{4}$-inch pipe at moderate pressure will supply enough water for a 5-horsepower engine and a 1-inch pipe is sufficient for a 40-horsepower engine, larger engines requiring proportionately larger supply pipes. The water supply pipe, shown at *a*, Fig. 8, should enter the engine at the point that is likely to heat most rapidly, generally at the exhaust-valve casing or cylinder head, and the outlet pipe *b* should emerge from the top of the cylinder jacket. The outlet pipe should discharge into a funnel *c*, in order that it may readily be seen whether the water is flowing or not, and that the temperature of the water may be better observed. The overflow pipe *d* should be one or two sizes larger than the supply pipe, in order that all the water that is brought to the engine pressure may flow off by gravity. Provision should always be made by a suitably placed drain connection *e* for emptying the cylinder jacket in cold weather, to guard against cracking of the jacket wall through the freezing of the water.

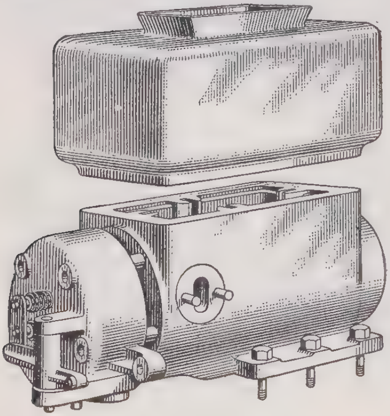

FIG. 9

42. Some manufacturers use what is known as the hopper system of cooling. In this system, shown in Fig. 9, the sides of the water-jacket are straight, leaving a large rectangular opening at the top, over the cylinder. The hopper, or water reservoir, is bolted to the water-jacket at this opening. This cooling system is especially adapted to stationary and portable engines such as are used on construction work and on the farm. No pump or circulating system is required, the only care necessary being to keep the water-jacket free from obstructions and to be

sure that the water in the hopper is never less than 4 or 5 inches deep over the highest point of the cylinder. Since the only loss is due to evaporation, a full hopper will run some time without attention. A drain cock is located at the lowest point of the water-jacket in order that the water may be drained off in freezing weather. If at any time it should become desirable to use forced circulation from a cooling tank, the hopper may be removed and the opening in the water-jacket covered with a plate in which is located the overflow or discharge pipe, the drain-cock opening being used to admit the water from the circulating pump.

43. Deposits in Water-Jacket.—If the cooling water contains lime or alkali, the heating of the water in the jacket will cause these solid substances to be deposited in the cooling spaces. This will soon choke any narrow ports, prevent proper circulation, and result in overheating, rapid wearing of the valves, and loss of power and efficiency. A simple remedy consists of the application, at regular intervals, of a dilute solution of hydrochloric, or muriatic, acid, made as follows: Dilute one part of muriatic acid with nineteen parts of water, and, after draining the jacket completely, pour in enough of the solution to fill the entire cooling space. Allow the mixture to remain in the jacket for not more than 8 to 12 hours, after which wash the cooling space thoroughly by running clear water through it. If the solution is permitted to remain in the jacket longer than the period stated, there is danger that the metal may be damaged by the action of the acid. The acid will soften and dissolve the lime or alkali, and the clean water will remove it from the jacket. It is generally sufficient to apply this method of removing the deposits once every two weeks. If neglected too long, the acid will not dissolve the deposit.

ASSEMBLING AND ADJUSTMENT OF PARTS

44. Shaft and Flywheels.—Before assembling any parts of the engine, they must be thoroughly cleaned of any dirt, dust, antirust, or packing material, and lubricated where necessary. After the engine bed has been securely placed upon

the engine foundation, the working of the crank-shaft in its bearings should be examined to see that it turns easily. Only very small engines are usually shipped with the shaft in place and the flywheels keyed to the shaft. If the wheels are shipped separately, they should not be put on the shaft until it has been ascertained that the latter does not bind in the journal-boxes. When lifted by hand, the crank should drop by its own weight from a horizontal position. The timing of the valves and ignition depends on the relative position of the teeth in the gears on the crank-shaft and cam-shaft, or other shaft that controls the ignition. As a rule, the gears are marked by ciphers or similar symbols, and must mesh so that the mark on the tooth of one gear comes opposite to a like mark on the space between two teeth of the other gear. This should be investigated before any attempt is made to put the wheels on the shaft.

45. See that the bore of the flywheels and the surface of the crank-shaft are clean. Then oil both parts with lubricating oil. Usually each wheel and each key is numbered, and care should be taken to place them so as to go on the side marked with corresponding numbers on the end of the shaft. If the weight of the wheels makes lifting by hand impossible, place planks on the floor underneath the crank-shaft, and roll the wheels up on these planks until the bore of the hub stands exactly opposite the end of the shaft. Then work the wheel gradually over toward the shaft until it rests against the end of the shaft. By a concerted effort of the men handling the wheel, it will then be easy to slide the wheel on the shaft for a distance of an inch or more.

46. In the case of very heavy flywheels where the force at hand is too small to handle them, wedges may be used, once the wheel has been brought opposite the shaft, to attain the proper elevation. With the bore opposite the end of the shaft, drive wooden wedges under the wheel, in its plane of rotation, until the bore is exactly in line with the shaft. When this position is reached, the wheel may be moved across the wedges with the aid of a pinch bar until the shaft has started to enter the bore.

The wedges used should be of such width as to allow the wheel to be shifted without danger of their tilting or slipping out. Now place a block of wood between the crank and the engine bed, so as to prevent the crank from moving when turning the flywheel to the right. Be careful, however, to place the wood so as to avoid danger of breaking the bed. Then, while one or two men hold and balance the wheel, turn it slowly and gradually around on the shaft toward the right, at the same time pressing it on the shaft until it is worked on the shaft the full length of the hub. Remember that the wheel has been on the shaft before, and if it is found that it sticks and refuses to turn, look for obstacles such as dust or chips, and take off the wheel at once before the bore of the wheel and the surface of the shaft are damaged by cutting. Wherever it is possible to use a chain hoist or a block and tackle to handle the wheel, one should be employed, as it not only lightens the work but also lessens the danger both to the wheel and to those handling it.

47. After the wheel has been put on the whole distance, turn it so that the keyway in the wheel stands exactly opposite the one in the shaft, and drive the key in by means of a sledge or a large-sized hammer. The keys should be well lubricated before being driven. If two keys are used in one wheel, drive them in gradually and evenly. Driving in one key at a time, all the way, will result in throwing the flywheel out and prevent it from running true. Care should be taken in striking the ends or heads of the keys with a hammer, as they may break off if not struck squarely.

48. It is sometimes found, after placing the wheel on the shaft, that it does not run true. This may be due to careless handling in shipping or unloading. The damage can be repaired and the wheel made to run true by careful hammering of the spokes near the hub. To ascertain which part of the wheel needs straightening, turn it slowly by hand, holding a piece of chalk on a rest close to the rim, thus marking the higher part of the rim. Then strike the spoke or spokes under this part of the rim with the blunt end of a medium-sized hammer. To avoid injuring the paint, hold a piece of sheet copper

against the part of the spoke with which the hammer comes in contact, and strike a spot about 2 or 3 inches distant from the outside of the hub.

49. Piston and Connecting-Rod.—The piston and connecting-rod are generally shipped detached, and, even if they are in position when the engine is received, it is advisable to disconnect the rod, take out the piston, and thoroughly examine both. Remove all antirust material used in packing by washing the surfaces in kerosene and rubbing with cotton waste. See that the outer surface of the piston is smooth, and that the edges have not been damaged in handling. If necessary, smooth off any slight ridges with emery cloth or a very smooth file. The closed end of the piston, which is exposed to the combustion, must be smooth and must not show any imperfections in the casting, such as blowholes or sandholes. Defects of this nature may easily cause premature ignition of the charge.

The piston rings should move easily in their grooves, without, however, any lateral play. If they stick, use kerosene freely, until any gummy oil or material has been washed away. If the piston pin that holds the piston and connecting-rod together is lubricated through a hole in the wall of the piston, see that this hole is clean and affords no obstruction to the flow of oil to the pin.

50. Clean both bearings of the connecting-rod, and after cleaning and giving a liberal coat of oil to the piston pin, insert it in the piston, with the rod held in place between the bosses inside of the piston. The inner walls of the latter should be free from any trace of molding sand, turnings, or filings that might find their way into the cylinder and cut the working surfaces. It is good practice to give the rough inner piston surface a coat of black fireproof asphaltum paint before the piston is placed in the cylinder. This should properly be done by the maker of the engine, but, if neglected, it will benefit the purchaser to have it attended to before any attempt is made to start the engine. Clean the interior of the cylinder and examine the condition of the working surface to make sure that it is

in perfect condition and shows no longitudinal scratches or ridges caused by the cutting of the piston.

51. After the piston pin has been inserted, tighten the setscrews and locknuts used for holding the pin in place. Apply a liberal quantity of cylinder oil to the outer surface of the piston, which is now ready to be placed in the cylinder. The end of the cylinder nearest the crank-shaft is usually tapered, so as to make it from $\frac{1}{8}$ to $\frac{1}{4}$ inch larger in diameter than the piston, to facilitate the insertion of the latter into the cylinder. The piston rings, being naturally expanded, must be compressed so as to enable them to enter the cylinder. In small engines this can be done by hand, while in larger pistons, it will be found more convenient to use cord or thin flexible wire with which to draw the rings together.

52. After the piston has completely entered the cylinder, move it backwards and forwards several times to ascertain whether or not there is any obstruction to prevent it from working freely. The cap of the crankpin bearing of the connecting-rod having been removed, the crank is now turned so as to bring the crankpin opposite its bearing, and the rod and piston are moved out until the bearing rests against the pin. Then put on the connecting-rod cap and tighten the bolts until the bearing is properly adjusted. Always use a liberal amount of lubricating oil on both pin and brasses before putting them together.

53. Valve-Gear Shaft, Valves, and Governing Mechanism.—In most cases either the crank-shaft or the secondary or cam-shaft is shipped detached from the engine, and must be put in place by the erector. As the time of opening and closing the inlet and exhaust valves, as well as the point of ignition, is determined by the cam-shaft, it is obvious that there is a certain relative position of the gears that drive the secondary shaft. These gears may be spiral, spur, or bevel gears, but in any case it is necessary that the teeth of the gears mesh so as to time the valves and ignition properly. This timing is done at the factory when the engine is assembled and tested,

and the maker generally marks the gears by letters, ciphers, or similar marks, one on the tooth of the driving gear and a corresponding mark on the space between the teeth of the driven gear.

54. When placing the shafts in their bearings, be sure to look for these marks, and put the gears together so that they mesh as intended. The maker of the engine is of course supposed to know the exact timing of the valves and ignition that will give the best results obtainable with his particular engine,

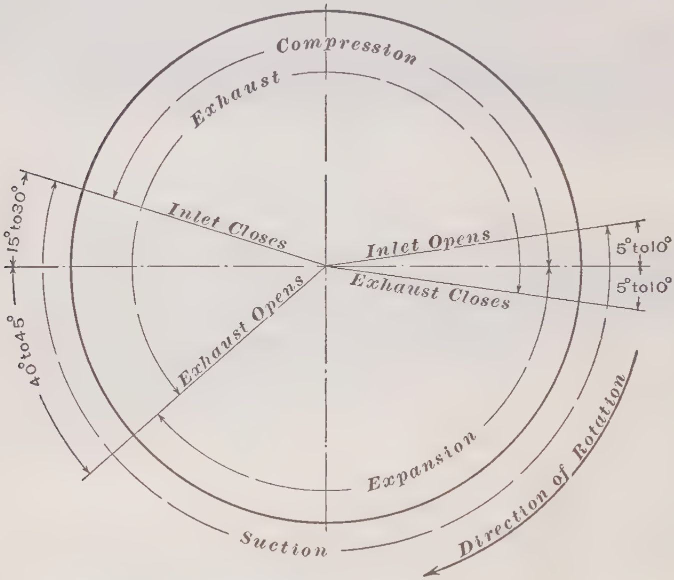

Fig. 10

considering its design, speed, etc., and no attempt should be made by the purchaser or attendant to improve the engine in this respect. Generally speaking, however, the exhaust valve should close at a point when the crank has passed the inner dead center, after the end of the exhaust stroke, by from 5° to 10°, as shown by the diagram in Fig. 10. The length of the cam or other similar device used for operating the exhaust valve will then determine the point of opening, which, in an engine of moderate speed, will be about 40° to 45° before the

crank reaches the outer dead center on the working, or expansion, stroke.

55. The inlet valve, if operated by a cam or a lever, generally opens a little before the beginning of the suction stroke, possibly 5° to 10°, so that for a very short period of time both inlet and exhaust valves are open, say during 10° to 20° of the crank movement. The inlet valve will generally be found to close, when the crank has passed the outer dead center, at the end of the suction stroke—to an extent of from 15° to 30°, depending on the fuel and other conditions. If operated by the partial vacuum inside of the cylinder, created by the outward movement of the piston during the suction stroke, the inlet valve of course opens and closes automatically, and the timing is regulated by the tension of the inlet-valve spring.

56. The timing of the fuel-admission valve, where the valve is mechanically operated by cam and lever or some similar device, depends on the kind and quality of fuel used, and also on the pressure at which it is supplied. With illuminating gas at the average pressure, the valve should open when the crank has passed the inner dead center about 15° and close about 30° after the crank has passed the outer dead center. The same timing of the air-inlet and fuel valves will be found to give the best results when using gasoline as when using illuminating gas, if the gasoline is supplied through a nozzle controlled by a small poppet valve actuated by cam and lever.

57. As natural gas is much superior to illuminating gas in heating value, a differently proportioned mixture is required, which is usually regulated by throttling the gas-cock on the engine so as to suit the quality of the fuel available. The timing of the fuel valve is the same, however, as when using illuminating gas, but the poorer qualities of gas, such as producer gas or fuel of correspondingly lower heating value, require a longer period of time during which the gas valve must be open. Generally, it will be found that, in order to get good results, the valve must begin to open at about 15° before the crank passes the inner dead center, previous to the suction stroke, and remain open until the crank has passed the outer

dead center about 40°. As stated before, these angles are only approximate, and they vary slightly according to the design of the engine, the area of the valves, and the speed at which the engine is operated.

58. After the cam-gear shaft has been properly placed and secured in its bearings, turn the engine over slowly and see that the shaft and the parts actuated by it move freely. Attach any levers, links, or rods that may not be in place when the engine is taken from the boxes, lubricating all pins and pivots carefully before putting them together. See that any valves closed by springs come to their seats quickly if pushed in by hand and released. Apply a liberal amount of kerosene to all valve stems, so as to remove any gummy or similar matter with which they may have become coated. Give special attention to the governor, on whose free movement depends the regularity of speed of the engine. All links and pivots connected with the governing mechanism should be washed with kerosene and then lubricated with a light oil of good quality.

59. Attachment of Lubricators.—Before attaching the lubricators furnished for oiling the cylinder, bearings, and principal moving parts of the engine, the oil cups should be carefully examined for any dust or other impurities that they may contain. See that they are perfectly cleaned before they are put in place and filled with oil.

The tapped holes for receiving the individual oil cups and the holes through which the oil is supplied to the parts to be lubricated should also be examined with great care, and any waste or similar obstructions that would tend to interfere with the supply of oil should be removed.

IGNITION SYSTEM

60. Battery and Spark Coil.—The matter of installing the battery, spark coil, switch, and wire connection deserves the most careful attention. The wire connections between the battery and the engine should be made according to the instructions sent with the engine to be installed. As a matter of fact,

the larger part of the trouble with internal-combustion engines is due to the ignition device and its connections. Some of these difficulties will occur even if every possible care is taken, but most complaints can be traced to neglect or carelessness in installation or ignorance in operation.

61. A good quality of insulated fireproof and weatherproof copper wire should be used to connect the individual cells of the battery and the spark coil with the battery and engine. Flexible rubber-covered or stranded wire is also permissible. In fastening the wires to the ceiling or walls, do not use metal clamps, which are liable to injure the insulating material, but use wooden or fiber cleats cut out to suit the thickness of the wire. Avoid splicing whenever possible; but, if it is necessary to employ splices, make them carefully and solder them securely. The wire should be of such length as to reach from 6 to 9 inches beyond the binding post to which it is to be connected. To avoid any pulling on the wire or post, the extra length should be coiled on a $\frac{1}{2}$-inch round rod, slipped off, and left as a spiral between the straight wire and the binding post.

62. Electrical Connections.—The spark coil must be set in a dry place and must be well protected from moisture, which causes short-circuiting and prevents ignition. All terminals of the wire connections must be clean and bright, to insure good contact. The connections between the cells should preferably consist of flexible insulated wire, with flat copper washers soldered to the ends, the hole in the washer fitting easily on the binding post. Connections of this kind may be purchased from almost any electrical supply dealer, if they are not already furnished with the engine.

As a rule, an ordinary two-pole, or two-point, switch with lever-handle contact will answer all purposes. These switches have the advantage of being easily examined and kept in order. Knife switches are equally well adapted for use in engine rooms, while if the switch is necessarily exposed to out-of-door atmosphere an enclosed switch, such as is used for incandescent lights, is more suitable.

63. Ignition Plug.—The ignition plug containing the electrodes must be examined as to cleanliness, freedom from corrosion, especially of the contact points, and easy movement of the movable electrode, before being attached to the combustion chamber. While the engine is at work, the plug, being exposed to the heat of the combustion, will expand slightly more than the surrounding walls. It is evident, therefore, that in order to be able to remove the plug in case of necessity, after the engine has been running for some time, it must, when cold, enter its aperture easily and without having to be forced. To make the packing surface of the plug tight against the pressure in the cylinder, a ground joint is used, which may be either flat or tapering, or a flat ring-shaped surface packed with sheet asbestos. In either case, the packing surfaces must be thoroughly cleaned before the plug is put in place and tightened up.

64. There are two methods of producing the spark with the make-and-break system. In one of these, known as the *wipe spark,* the movable electrode wipes across the stationary electrode, the latter being in the form of a leaf spring. In this system the movable electrode makes a complete revolution for each ignition and it is claimed that the constant wiping keeps the contact surfaces clean. This ignition also has the advantage of an open circuit except during the time of actually making and breaking the contact.

In the second method, known as the *hammer break,* the electrodes are together and the circuit is closed, except at the time of firing, when they are separated and the spark occurs. With this system it is best to use a magneto, or a small dynamo, as the closed circuit would rapidly run down a battery.

The jump-spark ignition used on some engines employs the ordinary spark plug as used with automobile engines. The fact that there are no moving parts passed through the cylinder walls is claimed as an advantage for this system. A revolving contact timer is employed in this system in place of the push rod of the make-and-break system. Care must be taken that the spark plug is always free of carbon and that the points are the proper distance apart.

65. The foregoing forms of ignition may only be used with engines burning the lighter oils, as kerosene or gasoline. For engines burning crude oil these methods are inadequate, due to high pressures used and the difficulty of vaporizing the oil. It is customary when using heavy oils, to force them into the cylinder in a fine spray and ignite them by the use of a red-hot bulb or chamber at the end of the cylinder, which is heated by the heat retained from the previous power stroke together with the heat of compression. This system has the disadvantage of taking some time in starting, as the ignition chamber must be heated by means of a torch; but the saving in fuel cost overbalances this disadvantage.

66. Point of Ignition.—The point of ignition varies in accordance with the quality of the fuel and the speed of the engine. At medium speed, when using illuminating gas or gasoline, the ignition should occur just before the end of the compression stroke, with the crank standing at about 15° to 20° below the inner dead center. Natural gas, as well as producer gas, the combustion of which is somewhat more sluggish, requires a different timing of the ignition, and the spark should occur when the crank stands about 22° to 25° below the inner dead center.

67. Testing the Electrical Connections.—The testing of the electrical connections may be said to complete the installation of the engine and put it in condition for starting. To determine whether the wires transmit the current in the proper manner, connect the battery, spark coil, switch, and engine as directed. Then, if a make-and-break system is used, disconnect the terminal attached to the fixed electrode, turn the engine to such a position that the two electrodes will be in contact, see that the switch is turned on, and wipe the end of the wire against the surface of the nut that holds the fixed electrode in place. If everything is in good order, a bright spark will then be produced. On the other hand, after turning the engine so that the contact between the two electrodes is broken, no spark should appear when the fixed electrode is touched and wiped in this manner; in wiping any other bright

part of the engine, however, a spark of similar intensity to that just referred to should be produced. If a high tension system is used the connections can be tested by removing the spark plug, laying it on the cylinder, and connecting it in the circuit. Then turn the engine over by hand and if a spark occurs at the plug the connections may be assumed to be correct.

OPERATION OF GAS ENGINES

STARTING THE ENGINE

PREPARATION FOR STARTING

68. Adjustment of Lubricators.—After the engine has been assembled and connected, the oil cups should be filled and tested to ascertain that the feeds work properly. The adjustment of the cups should at first be such as to supply a rather liberal number of drops; later, the quantity of oil may be cut down to the normal amount, after it has been demonstrated that the bearings run cool. In a vertical engine using splash lubrication, fill the oil well in the base until the ends of the connecting-rod bolts dip about $\frac{1}{2}$ inch into the oil when the crank stands at its lowest point. Make sure that all links, levers, and pivots have been lubricated, that the valves and ignition mechanism move freely, and that the water supply circulates properly.

To make certain that the crankpin and the piston pin are properly lubricated before starting, apply a small quantity of oil to each by hand, without relying on the lubricator or mechanical oiler provided for the purpose of oiling these parts while the engine is running. Sometimes these devices may fail to perform their functions as promptly as is necessary, and a hot bearing may result, causing serious trouble that could have been easily avoided by taking this simple precaution.

69. The oil wells of the ring-oiling bearings should be filled to the proper height, and it should be ascertained that

the oil ring or chain moves freely, so that it will distribute the oil over the journal surface when the shaft revolves. Wiper oilers must be adjusted so that the moving element of the device touches the stationary part of the oil cup only lightly enough to wipe off any drops of oil suspended from the metal tip or wick of the feeding device. If the wiper scrapes too hard against the tip of the cup, it will waste oil and throw it over the engine.

Worm or spiral gears, which are often employed to transmit motion from the crank-shaft to the cam-shaft, are usually run in an oil bath. The casing containing these gears must therefore be filled with oil before starting.

Where a pump is used for forced lubrication, care should be taken to see that all parts of the pump are in good working order and that all valves work freely. The packing in the stuffingbox should be tight enough to prevent oil from working out along the plunger but it should be borne in mind that it is possible to tighten this packing so much that excessive energy will be consumed in moving the plunger.

70. Examination of Piston.—Examine the way in which the piston works in the cylinder. A proper fit of the piston is of the utmost importance, in order to obtain good service from the engine. It must move freely, but at the same time must prevent any loss of pressure during the compression and expansion strokes. When turning the engine by hand, there must be no hissing sound during the compression; this would surely indicate a defective piston or improperly fitted piston rings. A perfectly fitted piston, tried in this way, will rebound before the end of the compression stroke is reached. In the case of a double-acting engine, where the piston and piston rod are cooled by circulating water through them, see that all connections are properly made and that the water will flow freely.

71. Examination of Valves and Igniter.—If the engine can be turned over easily through the compression stroke, it will be difficult or impossible to start it. The loss of pressure, however, which prevents proper compression, is not

likely to be due to an imperfect piston, especially in a new engine, but rather to a valve that leaks or to leakage about the movable electrode or the spark plug. It is well, therefore, to ascertain the cause of such a leak, by thoroughly examining the inlet and exhaust valves and the igniter. Possibly one of the valve stems or the electrode may stick in the guide, or there may be an obstruction on one of the valve seats. Where packings are used, one of them may have been damaged or partly blown out.

72. An application of kerosene to the valve stem will wash away any thick oil, grease, or similar substance that may cause the valve to stick. If impurities have been deposited on the valve seat, they can usually be removed by lifting the valve by hand and cleaning the seat with a scraper or some similar tool. In using a scraper or other edged tool, care must be taken not to mar the bearing surface of either the valve or the valve seat. In the case of larger valves seated in casings too heavy to be handled conveniently, the valve may have to be taken out before the seat can be examined and cleaned.

The renewal of a packing, especially when the packing surface is of considerable size, is a more serious matter, and should not be undertaken until a careful examination has shown the necessity for doing so.

73. Means of Starting. — Small engines are often started by hand, simply requiring the opening of the fuel cock and the turning of the flywheel until the charge thus admitted is ignited, giving the engine an impulse sufficient to carry it over the following strokes of its cycle until subsequent charges are admitted and ignited. In this manner, the engine reaches its full speed when from ten to twenty explosions have taken place, the number of explosions depending on the weight of the flywheel. An engine equipped with heavy wheels requires, naturally, more impulses before attaining full speed than one with light wheels.

74. Difficulties in Starting.—Difficulties in starting usually met with in practice may be due to various causes. Above all, it must not be supposed that an engine that has run

regularly for a period of time will refuse to run without cause, and the origin of the trouble should be located as speedily as practicable. The most common sources of trouble in starting are improper proportion of the constituent parts of the mixture, failure of the ignition and its connections, or loss of pressure during the compression and expansion strokes. A proper proportion of air and fuel is of great importance to prompt and effective combustion. It should be remembered that when starting by hand, with the piston moving slowly, the fuel valve remains open for a longer period of actual time than when the engine is running at its normal speed. The fuel being usually supplied under a certain amount of pressure, while the air is drawn from the atmosphere, it follows that, with the engine turning slowly, the proportion of fuel to air is greater under these conditions than under normal working conditions. This condition is made still worse when the inlet valve is of the automatic type, being opened by the partial vacuum created in the combustion chamber by the outward movement of the piston.

75. Regulation of Mixture in Starting.—In order that the quantities of air and fuel may be regulated so as to admit a mixture of the proper quality, the fuel cock should be only partly opened during starting. The cock or throttle being usually fitted with a graduated dial, the operator will be able after a few trials to determine at which point of opening the engine will start readily. When using illuminating gas, this point will vary in accordance with fluctuations in pressure that may occur at different times of the day.

76. A common mistake made by inexperienced operators is to admit too much fuel to begin with, and if the engine naturally fails to ignite, to open the fuel cock still further and thus aggravate the trouble. This applies equally well to gaseous and to liquid fuels. As a result of opening the fuel supply too wide, the combustion chamber becomes flooded with gas or vapor, and conditions are not improved until the supply has been shut off completely and the engine turned over several times, so that the contents of the cylinder are expelled through the exhaust pipe.

77. When the engine is operated with illuminating gas, it will generally be found necessary first to open the valve in the pipe back of the gas bag, let the bag become inflated, then shut off the valve, and start the engine on the pressure exerted by the gas contained in the bag and pipe between it and the engine. As soon as the bag shows signs of becoming empty, which will occur after a few explosions, the fuel cock must of course be opened.

When gasoline is used, the air can vaporize only a certain quantity of fuel. Any excess will be deposited and will accumulate in the inlet passages and in the combustion chamber, and the longer the wheels are turned with this excessive opening of the fuel supply, the more aggravated will the trouble become. Frequently, if under these conditions the fuel supply is shut off completely and the turning of the wheels is continued, an explosion will occur as soon as the amount of fuel carried into the cylinder is reduced to the point where a properly constituted mixture is formed.

78. In a well-designed engine, the fuel cock is proportioned so that it must be opened full, in order to obtain a perfect mixture with the engine running at full speed. Engines with air-inlet valves positively operated by means of cams and levers are less liable to failure in starting caused by improper proportions of the mixture. This is due to the fact that in such engines the air-inlet valve and the fuel valve are open during the same period of time, thus regulating to a certain extent the quantities of air and fuel forming the charge.

79. In engines operated on liquid fuel, such as gasoline, kerosene, etc., the fuel must be pumped by hand until a sufficient quantity is raised from the supply tank to the level of the fuel-admission valve to start the engine. The fuel is generally pumped into a small cup provided with an overflow pipe, which returns to the supply tank any excess amount of fuel over that which fills the cup to a certain level. This cup and overflow device may be a part of the fuel valve or it may be separate.

80. When first starting the engine, it may require quite a number of strokes of the fuel pump before the air in the

suction pipe between the tank and engine is pumped out and the liquid delivered to the valve. If there is difficulty in pumping the fuel, it is a sure sign of leakage of air in the supply pipe; if the liquid does not stay in the cup after being pumped up, it indicates that there is leakage at some point between the cup and the engine. Before attempting to run the engine, therefore, the pipes and connections should be carefully examined, the leak located, and any imperfect joints made tight.

81. In the modern gasoline engine, a mechanically operated device, which determines the exact amount of fuel sprayed into the air, atomizes the gasoline while entering the mixing chamber at a certain velocity. It is therefore evident that the forming of a proper mixture and the consequent prompt starting are not dependent on atmospheric conditions and quality of the fuel to the same degree as when the old type of vaporizer was used. Nevertheless, in extremely severe weather, in locations where the engine room is not kept warm during the night, and especially when the fuel used is of comparatively low specific gravity, it may become necessary to aid the atomizing of the gasoline by heating the combustion chamber in some manner before starting can be attempted. The quickest and safest way is to heat the carbureter or mixing valve by wrapping around it cloths wrung out in hot water, or hot water may even be poured over the carbureter or mixing valve if care is taken to cover all air passages so that no water may enter them.

82. No set rules can be laid down that will tell the operator just how to obtain a perfect mixture at all times. This depends on the design of the engine and on the conditions surrounding each individual case, which may necessitate a different method from that which must be observed in another engine of the same type or make. Indications of a good mixture will manifest themselves to an observant operator by the sound of the impulse and the appearance of the exhaust at the end of the exhaust pipe. A smoky exhaust is a certain sign of an excessive amount of fuel, and a mixture of this kind also produces a weak impulse. If the exhaust is clear and the

admission of several charges in succession is required before an explosion occurs, the indications are that the fuel is not admitted in sufficient quantity. This condition also manifests itself by back firing or explosions in the air pipe and passage, caused by retarded combustion of the charge, the mixture being still burning at the end of the exhaust stroke and igniting the incoming charge while the inlet valve is still open.

83. Regulating Gas Pressure.—Engines operated with illuminating or natural gas require the same degree of judgment in determining the amount of fuel to be admitted while starting the engine as does a gasoline engine. If illuminating gas is used, the pressure is regulated at the gasworks, and any slight fluctuations are equalized by use of a rubber bag, as already explained. When running with natural gas or producer gas, the pressure is frequently regulated by a small gasometer, as illustrated in Fig. 11, consisting of a tank *a* partly filled with water in which is submerged a float *b*, closed at the top and open at the bottom. The gas-supply pipe *c* from the main enters the gasometer at the bottom and extends through the water into the float, while the pipe *d* connecting the gasometer to the engine is attached in a similar manner. The float *b* is connected to the valve *c* in the supply pipe in such a manner that, when the float becomes filled with gas, it rises and closes the valve *e*. As soon as the engine takes a charge of gas from the gasometer, the float *b* descends, and in doing so opens the valve *e* far enough

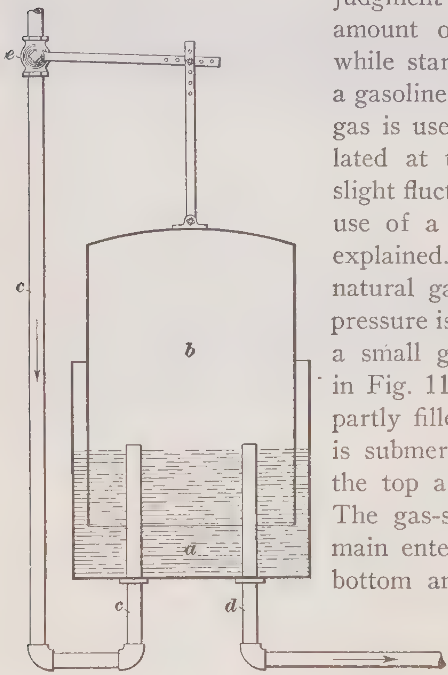

Fig. 11

to replace the amount of gas consumed by the engine. According to the existing conditions, the pressure exerted by the weight of the float may be increased by placing weights on top. The operator will learn by experience just how far the dial cock on the engine must be opened to make prompt starting possible.

84. Timing the Ignition.—A very important feature to be observed in starting an engine is the proper timing of the igniting device. Electric igniters are equipped with a retarding device that allows the breaking of the contact between the two electrodes and the resulting spark to occur after the crank-shaft has passed the dead center at the end of the compression stroke, and thus prevent the engine from turning backwards suddenly while the flywheels are being turned by hand. It is therefore necessary to be sure that the spark has been set in starting position, to avoid possible injury to the operator. To lessen the liability to accident in case of unexpected reversing of the engine while starting, it is advisable to avoid placing the foot on the flywheel spokes when turning it by hand. If the engine is properly lubricated, and the relief valve generally provided for the escape of a part of the compression pressure during starting is working properly, it is always possible to turn an engine up to 30 horsepower by hand without putting the foot on the spokes of the flywheel.

85. This precaution in timing the point of ignition applies to electric ignition of the make-and-break contact as well as the jump-spark method. In the latter case, the timing device, which regulates the moment of ignition, must be adjusted so as to make the spark sufficiently late to prevent reversing of the engine; hence, a plainly visible mark of some kind should be provided that will tell the operator just how the timer must be set.

In case of failure to ignite, first see that the vibrator of the coil is working properly when the current is on. Also detach the wire connected to the plug, and test the distance the spark will jump by holding it close to any metal part of the engine. In doing this, it must be remembered that a spark will not

jump as far when exposed to the high-compression pressure in the cylinder as it will in the open air. It should therefore be capable of jumping a gap of about $\frac{5}{16}$ to $\frac{3}{8}$ inch when tested on the outside of the cylinder.

If the spark is found to be satisfactory, take out the plug and note the condition of the spark points, removing any carbon deposit or other impurities that may have accumulated there. Also see that the insulators are in good order, that they have not been cracked, and are free from grease; if necessary, cleanse them by washing with gasoline before putting them back in the plug.

CARE AND MANAGEMENT OF ENGINES

CARE OF ENGINE PARTS

86. In order to insure reliable service an engine should be given the necessary care regularly. Those parts that contribute principally to the proper operation of the engine, such as the igniter, valves, governor, bearings, and lubricators, should be inspected at regular intervals.

IGNITER

87. Under ordinary conditions of service, when running about 10 hours a day, the igniter should be taken out once a week, the contact points examined, and, if necessary, cleaned or dressed. There must be no leak past the seat of the movable electrode, and as soon as any leak occurs at this point, as indicated by a hissing sound, the electrode must be taken out and ground to a perfect seat with fine emery powder and oil.

The stationary electrode is usually insulated with mica, porcelain, or lava washers or bushings, and packed with asbestos, so as to make it tight against the pressure of the explosion. If the packing of this electrode is damaged, the steel pin itself will be exposed to the intense heat of the burning charge. A gas leak will appear around the pin, and when trying to overcome this by tightening the nut at the end of the pin, the heated

steel will be reduced in size. If this is repeated a few times, the pin will soon be useless. It is evident, therefore, that the fixed electrode must receive particular care in regard to preserving perfect insulation and tight packing. Mica insulators are probably best, as they are not liable to cause short circuits and consequent interruption of the service, by cracking, to which porcelain or lava bushings are subject. They also have the advantage of being sufficiently pliable not to require any asbestos washers to make them tight.

POPPET VALVES

88. There should always be a clearance between the end of the valve stem and the lifter operating it, so as to make certain that the valve can come to its seat, even after it has become expanded by the heat while in operation. It is a safe plan to follow the directions of the maker as to the amount of clearance to be allowed. Repeated grinding will reduce the amount of clearance, and adjustment must be made by slightly withdrawing the setscrew usually provided in the end of the lever.

Inlet valves are naturally kept more or less cool and clean by the incoming mixture, and require grinding less frequently than exhaust valves. Inspection and thorough cleaning once a month, however, are advisable. Automatic inlet valves, opened by the suction during the outward stroke of the piston, must move freely in their guides; any deposit of carbon or gummy oil will tend to interfere with their proper working. Kerosene applied to all valve stems at regular intervals will aid in keeping the stem clean and prevent it from sticking. The nuts and locknuts on the end of the valve stem, which keep the spring in place, must be kept tight. Carelessness in this matter may cause the valve to be drawn into the combustion chamber, where it may cause serious damage to the cylinder or piston.

89. If the inlet valve is operated by cam and lever, the same precaution as to a small amount of clearance between the end of the stem and the lever must be observed, as referred to in connection with the exhaust-valve stem. The inlet-valve

casing usually has a ground joint that requires the same care as the valve seat.

When using gas, the fuel valve operates under much the same conditions as the inlet valve just referred to. The same directions for cleaning and adjusting will therefore apply to this valve. Gasoline poppet valves are often fitted with small stuffingboxes packed with wick saturated in a mixture of soft soap and graphite powder. Care should be taken to keep the stuffingboxes tight enough to prevent any leakage of gasoline past their stems, but not so tight as to prevent the springs from closing the valves promptly. It will be found that a brass gasoline-valve stem will give better service than a steel stem, as the packing material has a tendency to cause the latter to rust and stick. The gasoline valve, however, must not be used where it will come in contact with heat.

GAS-COCK

90. The gas-cock, or throttle valve, generally consists of a cast-iron casing, a brass plug, having an opening through which forms the valve, and a graduated dial, with a handle to open and shut the cock. In order to be able to move the plug easily, it should be lubricated occasionally with a thin coat of oil and graphite. The screws that fasten the dial to the body of the throttle valve and hold the plug in position must be tightened evenly, so as to avoid leakage of gas at this point. When using natural or producer gas, which is usually not so pure as illuminating gas, it will be found necessary to clean the gas-cock, as well as the gas-valve stem and casing, more often. Kerosene will be found useful for this purpose.

GASOLINE PUMP

91. Owing to the fact that gasoline vaporizes easily, it is more difficult to lift it by means of a pump than it is to lift water. The condition of the gasoline pump is therefore of great importance in getting good results from a gasoline engine. The plunger must be packed well with suitable material. Lamp wick or asbestos wick thoroughly saturated with a mixture of

soft soap and graphite has proved an excellent packing for the stuffingbox of the gasoline pump. The valves, whether they are standard-type check-valves or flat-seated valves fitted with leather washers, must be kept free from impurities that may lodge on the valve seats and cause the pump to become air-bound, when it will naturally refuse to work. When possible it is best to use the pump as a force pump rather than to lift the gasoline. This, however, would necessitate placing the pump low enough for the gasoline to flow to it by gravity, which is not always convenient or possible. Filters used in the gasoline supply pipe, before it enters the pump, must be taken apart occasionally, and any impurities that may have gathered there must be removed, so as to afford a free passage to the fuel.

GOVERNOR

92. A steady speed is largely dependent on the working of the governor and its attachments. To insure good results in this respect, the levers and links of the governor must work freely, and at the same time there must be no lost motion in any of these parts. A thin lubricating oil should be used on all governor parts, and at regular intervals the whole governor should be taken apart, its pivots, levers, etc. cleaned by washing with kerosene or gasoline, and put together again after applying a liberal amount of lubricating oil. In most engines, the speed is adjusted by the tension of the governor springs, a higher speed being obtained by increasing, and a slower speed by decreasing, the tension of the springs. It is not advisable to increase the speed of an engine beyond the normal number of revolutions without first consulting the manufacturer.

STARTING DEVICES

93. Self-Starters.—To obviate turning the flywheels by hand, which in engines of the larger size would be inconvenient, if not impossible, most builders equip engines of more than 40 horsepower, and sometimes even smaller sizes, with self-starting devices, consisting of hand pumps for compress-

ing the explosive mixtures in the combustion chamber, and detonators or sparking devices for firing these charges by hand.

In a gasoline engine, the charging pump is usually attached to the side of the cylinder and is fitted with a small receptacle at the top or bottom containing a quantity of gasoline, over which the air is drawn before being forced by the pump into the cylinder. The air valve is automatic, and is held to its seat by means of a spring, the tension of which limits the lift of the valve and the amount of air pumped into the cylinder.

The charging pump of a gas engine takes the fuel from a small pipe connected to the gas supply, the gas being mixed with air while entering the pump cylinder through a series of small holes in the seat of the inlet poppet valve. Before charging the cylinder, the detonator, if one is used, must be charged with a parlor match, a portion of the wood being removed so that only the head end is inserted in the end of the detonator.

94. In order to start the engine properly, it must be turned until the beginning of the working, or expansion, stroke is reached. At this point of the cycle, the engine has just completed the compression stroke and the exhaust cam is about 180° away from the roller that operates the exhaust valve. With the crank in this position, the mixture is forced into the cylinder by giving a few quick strokes with the handle of the pump piston. This will put sufficient pressure in the cylinder to start the flywheels; then, as soon as the wheels begin to turn, strike the detonator, which will fire the match previously inserted. The resulting explosion will turn the crank over several revolutions if the mixture pumped into the cylinder is of the proper composition.

If too much or not sufficient fuel is admitted with the air, the explosion will be weak or the engine will miss fire altogether, and it will be necessary to try a different mixture of fuel and air. A few trials will demonstrate to the operator just how much gasoline should be put in the receptacle, or how far the gas throttle should be opened.

95. Compressed-Air Starters.—The method of using the pressure of compressed air in a storage tank to start the engine is probably the most convenient. Its only disadvantage is the possibility of the air supply becoming exhausted by leaks in the tank or connections or through repeated failures to start the engine because of faulty mixtures or other causes. This disadvantage is of course increased if the air compressor is operated from the engine itself or from a line shaft operated by the engine. The exhaustion of the air in the tank is of less consequence if the compressor is driven from a small auxiliary engine, the only difficulty in that case being the delay caused by the loss of time required for charging the air storage tank to the required pressure.

96. The operation of compressed-air starters is much simplified if the engine is equipped with a mechanically driven and timed valve that admits the air to the cylinder during what is usually the expansion stroke of the engine, and allows it to escape during the regular exhaust stroke. In this case, all the operator has to do is to open the cock in the air pipe between the tank and the engine, and keep it open until the engine has attained a fair speed; then the air connection is shut off and the fuel supply is turned on. If no mechanically operated timing valve for compressed air is provided, it becomes necessary to open and close the cock between the air tank and the engine by hand, at proper intervals, which requires a certain amount of skill and watchfulness on the part of the attendant, since it is necessary to have the cock closed except during the working stroke of the piston.

A very effective method, employed on large engines especially, is to admit air during every forward stroke of the piston and expel it during both the compression and the exhaust strokes. This is done by providing auxiliary cams that, when thrown in gear while starting, will open the inlet valve during the suction and expansion strokes, and the exhaust valve during the compression and exhaust strokes. After the engine is under way, the cams are disengaged and the engine is run in the regular manner.

97. In order to be always in a position to start the engine promptly, it is important for the attendant to keep the air compressor and storage tank in good working order. The compressor requires lubrication at regular intervals, and the air valves must be kept tight to insure efficient service. The pressure in the tank must show no perceptible loss overnight, and if it falls to any great extent, the cause of the leak should be determined and the proper remedies applied. If the leak is located in the seams or rivets of the tank, they must be calked in the usual manner. In case the pipes or fittings between the tank and the engine are not tight, they must be screwed up or defective fittings replaced with perfect ones.

LUBRICATING DEVICES

98. Care of Lubricators.—Intelligent care of the lubricating devices of a gas or gasoline engine is essential to efficient and reliable service. Sight-feed lubricators or drop oilers of the standard types require attention on account of the fact that the amount of oil supplied to the piston or bearings may vary slightly according to the quantity of oil contained in the cups. If nearly empty, they will supply a smaller number of drops than when full, and it is therefore well to keep them always filled. The temperature of the engine room also has some effect on the rate of feed, and in very cold weather the oil should be warmed before pouring it into the lubricators.

Force-feed lubricators supplying oil through tubes to the various bearings are more positive in their action in regard to the quantity supplied under varying conditions. Care should be taken, however, to guard against waste or other impurities settling in the bottom of the reservoir, whence they may easily be carried into the oil pipes and interfere with the free flow of oil to the parts to be lubricated.

99. Level of Oil in Crank-Case.—In engines using the splash method of lubrication the level of the oil in the crank-case should be maintained at a uniform height, as indicated by the gauge glass usually provided. While it is necessary

to keep the oil level sufficiently high to insure good lubrication, it is equally important not to allow it to become too high, because in that case the surplus oil is carried past the piston, and is not only wasted but becomes a source of trouble by depositing itself on the ignition points and causing them to work irregularly. It may be observed, however, that the fitting of each individual cylinder and piston has some effect on the amount of oil thus carried into the combustion chamber. It will therefore be found that the oil level that must be maintained in order to get sufficient lubrication of the piston may vary in two engines of the same make and size, and in all cases great caution should be exercised to carry the oil up to such a level that there will be no doubt about sufficient lubrication. After the proper level has once been determined by experience, the oil gauge should be marked, so as to show at a glance whether the oil is up to the required height.

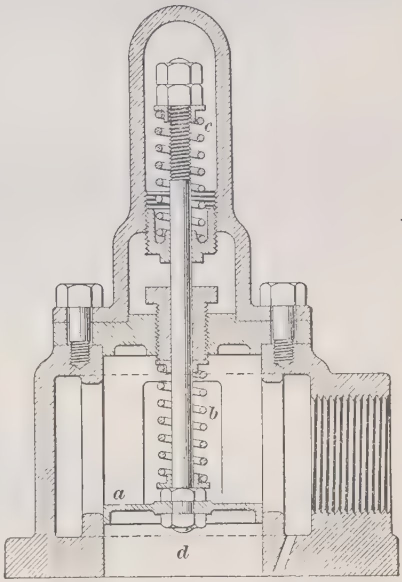

FIG. 12

100. Pressure in Crank-Case.—In some vertical four-cycle engines that use the splash system of lubrication, the escape of oil past the main bearings, due to the pressure produced by the movement of the piston, is guarded against by the use of a check-valve, a sectional view of which is shown in Fig. 12. The valve casing is attached to the crank-case, and the valve *a* is made adjustable, the tension of the springs *b* and *c* being varied so that the valve just closes the port *d* communicating with the crank-case when the engine is not running. When the engine piston moves downwards, the increase in pressure in the crank-

case opens the valve, affording a relief for the surplus pressure. On the upward stroke of the piston, the partial vacuum closes the valve and prevents any air from being drawn in.

101. Renewing the Oil.—The oil in the crank-case should never be left more than a week without inspection. Generally, it will have become thick and unfit for use by that time and should be removed. If there is a leak of exhaust gases past the piston, the oil in the crank-case will mix with the water from the gases and may become charged with acid from the sulphur that is present in these gases. This must be prevented, as the acid will gradually corrode and pit the journals of the crank-shaft and other moving parts with which it comes in contact.

ROUTINE OF MANAGEMENT

102. To avoid mistakes or oversights in starting, caring for, and stopping engines, the operator should adhere to a certain routine while performing his duties. The following rules in regard to the order in which the various operations in starting and stopping should be performed may prove of value.

STARTING THE ENGINE

103. 1. Attend to all lubricators and oil holes, always following the same order.

2. Apply a few drops of kerosene to the valve stem.

3. Open the gas-cock back of the rubber bag or regulator, or, when using gasoline or oil, open the cock near the tank, and work the pump by hand until the liquid appears in the valve or overflow cup.

4. See that the electric igniter is properly connected; turn on the switch and see that the spark is of proper intensity; or, in case of hot-bulb ignition, light the burner that heats the bulb.

5. Turn the flywheel until the engine is at the beginning of the working stroke.

6. Open the fuel cock to the point that has been found most reliable for starting.

7. Throw the relief cam in gear or open the relief cock.

8. If a compressed air or some other self-starter is employed, operate the device in accordance with the instructions given in previous paragraphs relating to this style of apparatus. If no starting devices are used, turn the flywheels rapidly until the engine starts.

9. Close the relief valve or disengage the relief cam and open the fuel cock to its full extent, gradually, as the speed of the engine increases.

10. Turn on the cooling water, if running water is used, or see that the tank is full and the cocks open if the tank system of cooling is employed.

11. Throw in the friction clutch or shift the belt to the tight pulley on the line shaft.

STOPPING THE ENGINE

104. 1. Disengage the friction clutch or shift the belt to the loose pulley on the line shaft.

2. Close the gas-cock near the rubber bag or regulator, or the gasoline or oil cock near the storage tank.

3. Close the gas, gasoline, or oil cock on the engine.

4. Throw off the switch between the battery and the engine, or turn off the burner that heats the hot bulb.

5. If there is danger of freezing, drain the water-jacket by closing the valve in the supply pipe and opening the cock that connects the bottom of the cylinder to the drain pipe. If water tanks are used, close the cocks in the water pipe and open the drain cock.

6. Shut off all sight-feed lubricators.

7. Clean the engine thoroughly, wiping off any oil or dust that may have accumulated on the engine.

8. See that the engine stops in a position where exhaust and inlet valves are closed. If necessary, turn the wheels by hand until this position is reached. It will protect the valve seats against corrosion.

OPERATION OF DIESEL ENGINES

105. Inasmuch as the Diesel engine differs from other forms of engines in its principle of operation and in its details of construction, it has its own peculiar operating troubles. Hence, to insure continuous and satisfactory running, it should have skilled attention. In the first place, the high pressures produced in the cylinders result in heavy pressures on the bearings, and as a consequence the bearing surfaces must be kept true, correctly alined, and well lubricated. Any looseness or slackness in the fit of the working parts will result in heavy pounding and rapid wear; hence, the adjustment of the working parts requires constant watching and skilled attention. As the ignition in the Diesel engine is due to the temperature caused by compression, it follows that the parts subjected to gas and air pressure must be kept absolutely tight. If this is not done, the engine may fail to act.

106. Because of the high pressures obtained in the cylinders of Diesel engines, the valves for the admission of air and fuel, the exhaust valves, the piston rings, and the gaskets between the cylinders and their heads require the care of an engineer experienced in dealing with high pressures. Furthermore, the temperatures produced in the cylinders are high, thus increasing the difficulties in the way of lubrication, and in some cases resulting in warping or straining that leads to further trouble. Auxiliary apparatus is required with this type of engine. There must be an air compressor to furnish the air for injecting the fuel into the cylinder, as well as for storing a supply of air under pressure, to be used when the engine is to be started. Fuel pumps must be used to supply fuel to the fuel valves. The governing apparatus must be accurately adjusted, as the amount of fuel admitted per stroke is small in volume. The operation of these auxiliary devices introduces still more problems for the engineer in charge of the Diesel engine.

107. Preparations for Starting.—Before a Diesel engine is started, the cooling water must be set in circulation through the jackets and cylinder heads. Care should be taken

to see that water is flowing through each of the jackets of a multicylinder engine, as an obstruction in one of the pipes may cut off or reduce the circulation to such an extent as to allow the cylinder to overheat. If the cooling system is open, that is, if the discharge from each jacket flows from the open end of the discharge pipe into a funnel or a conduit, any stoppage may easily be discovered. If the cooling system is closed, that is, if the cooling water is led to a cooling tower and then recirculated through the jackets, close watch should be kept on the temperature of the water discharged from each cylinder, so as to detect any evidences of overheating. The supply of lubricating oil in the crank-case should be ample for splash lubrication, and the supply of oil in the force-feed system for lubricating the pins and bearings should be inspected, to make sure that the engine will be properly lubricated.

108. Starting a Diesel Engine.—The Diesel engine is invariably started by admitting compressed air to the cylinder from a storage tank in which the air is kept under heavy pressure. If the engine is of the single-cylinder type, the starting valve is inserted through the cylinder head; if the engine is of the multicylinder type, only one of the cylinders is fitted with a starting valve. The opening of the starting valve is controlled by a special starting cam on the cam-shaft, and the construction is such that when the starting cam is put into action, the cam that controls the opening of the fuel valve is thrown out of action; thus, the starting valve and the fuel valve cannot be open at the same time. The flywheel is turned over by hand by the use of a pinch bar or some form of barring gear, until the crank is just beyond the upper dead center. Then the valve in the air pipe leading from the compressed-air tank is opened, and the engine is allowed to make several revolutions under the pressure of this air. Then the starting cam is shifted out of action, which brings the fuel-valve cam into action, and the engine takes up its operation in the usual way.

109. If the engine is being run for the first time after being set up, it is well to turn the crank-shaft through two or three revolutions by means of the barring gear on the flywheel.

This preliminary turning over will show whether there is any interference of parts. If everything seems to be in order, the engine should be started, in the manner just described. The load should not be thrown on at once. Instead, the engine should be run for a few hours under no load, to allow the journals and pins to wear to a good running fit in their bearings. Then the load may be applied gradually until the engine is running under about half of the full-load capacity. If no troubles develop during this period of operation, it may be assumed that the engine is working properly, and the load may be increased to the normal rating of the engine. It is advisable to take indicator cards from each cylinder during the preliminary running, so as to determine whether the load is equally distributed among the cylinders, and whether the combustion and the timing are satisfactory.

110. Equalizing Work in Cylinders.—In the case of a multicylinder engine, the indicator cards taken from the several cylinders at any one instant should show approximately the same areas, indicating that equal amounts of work are being performed in the cylinders; also, the shapes of the cards should be very much the same, indicating that the conditions of valve timing and combustion are practically alike in all of the cylinders. The valves should be so timed as to give the same compression pressure in each cylinder, and the same quantity of fuel should be injected into each cylinder, so that the combustion pressure, and consequently the work done, will be the same. If the pressures developed are unequal, the turning effort on the crank-shaft will be irregular, and those bearings subjected to the greatest pressure will wear more than the others. The result of unequal wear will be springing of the crank-shaft, which, combined with the uneven turning moment, will produce severe stresses in the shaft and may eventually cause breakage. Some engineers check up the alinement of the crank-shaft bearings regularly at short intervals, and correct even slight differences due to wear.

111. Timing of Fuel Valve.—The timing of the fuel valve in the Diesel engine depends on the position of the cam

that operates the valve, and this cam is capable of being shifted so as to alter the valve timing. To aid in adjusting the cam, it will be found advantageous to figure out the amount the cam must be moved to produce a given variation in the timing of the valve. It is usual to take the rim of the flywheel as a guide in adjusting the fuel-valve setting, and to calculate the fraction of an inch of movement of the cam corresponding to 1 inch of movement of a point on the flywheel rim. This fraction of an inch is found by dividing the diameter of the cam by the diameter of the flywheel, both taken in inches. For instance, suppose that it is found that the fuel-inlet valve opens too late, and that the amount of lateness corresponds to a movement of $1\frac{1}{2}$ inches on the face of the flywheel. If the cam is 4 inches in diameter and the flywheel is 4 feet in diameter, the ratio of diameters is $\frac{4}{48}=\frac{1}{12}$, which means that the cam must be shifted $\frac{1}{12}$ inch, measured on the surface of the cam, to produce a change of 1 inch in the valve timing, as measured on the face of the flywheel rim. Hence, the cam movement corresponding to $1\frac{1}{2}$ inches on the flywheel is $1\frac{1}{2}\times\frac{1}{12}=\frac{1}{8}$ inch. As the valve opening is late, the fuel-inlet cam must be shifted forwards $\frac{1}{8}$ inch to correct the valve timing.

112. The fuel-inlet valve usually is a comparatively slender needle, which is raised by the action of the lever operated by the fuel-inlet cam and closed by the action of a spring. At the upper end, where connection is made to the spring cap or spindle, the valve stem is held by a locknut, and the needle valve may be adjusted with great accuracy by turning this nut in one direction or the other. In order to determine just when the fuel valve opens, air is admitted from the storage reservoir to the fuel atomizer, and the valve in the air pipe is then closed, thus causing air under pressure to be left in the fuel atomizer. The engine is then turned over slowly by barring the flywheel, and in the meanwhile the indicator cock is left open. At the instant the fuel-inlet valve begins to open, there will be an audible escape of air through the indicator cock, and in this way the timing of the fuel-inlet valve can be determined with considerable accuracy.

113. Fuel-Valve Troubles.—The face and the seat of the fuel-inlet valve should be kept smooth and clean, so as to prevent leakage. If the beveled face of the needle becomes scored, it should be smoothed with fine abrasive. If the smoothing operation alters the shape of the face to any appreciable extent, the timing of the valve should be tested, to see that the fuel is injected at the proper moment, which is just before the crankpin passes the upper dead-center position. The fuel-inlet valve should be handled carefully, for if it is bent or otherwise damaged, it will not work properly, and a slight fault in the action of this valve will have considerable influence on the efficiency of the engine. Occasionally the needle may develop a tendency to stick. This may be due to overheating of the cylinder head through obstructed circulation of the cooling water; or, it may be caused by the formation of tarry material produced by imperfect combustion; or, the stuffingbox gland surrounding the needle may be set up too tightly. The remedy for a sticking needle is to clean the face and the seat, and to have the packing set up only tight enough to prevent leakage. Graphite forms an excellent lubricant for the needle in its stuffingbox.

114. Leakage.—The effect of leakage in a Diesel engine is to reduce the compression, thus decreasing the resulting temperature and rendering the combustion of the fuel imperfect. As the pressure developed is high, great care should be taken to prevent leakage. There are four valves opening into the combustion chamber of a four-cycle Diesel engine, namely, the air-inlet valve, the exhaust valve, the starting valve, and the fuel-inlet valve. All of these should be inspected regularly, and if found worn they should be reground. The exhaust valve, of course, is the one most likely to develop trouble, because it is subjected to the heat and the erosion of the hot gases. If the fuel-inlet valve leaks, the efficiency of the engine will be impaired, because ignition will occur too early; also, the engine will probably develop a tendency to knock. Any fault in the time of ignition may be discovered by taking indicator diagrams. In the two-cycle Diesel engine, there is no atmos-

pheric air-inlet valve, and in some types the exhaust valve is replaced by exhaust ports. With such construction, the chances of valve leakage are decreased. On the other hand, scavenging-air valves are sometimes placed in the cylinder head, and these must be kept tight.

115. Another point at which leakage may develop is at the joint between the cylinder head and the metal liner of the cylinder. This joint is subjected to the compression pressure and to the pressure produced by combustion, and must therefore be well made. The joint surfaces are carefully and accurately machined and a thin copper gasket is inserted between them, this gasket being compressed when the cylinder-head bolts are drawn up. Again, there is a possibility that leakage may occur past the piston. To prevent this, the upper end of the piston is grooved to receive from four to six piston rings, the ones near the top being given greater clearance because they are subjected to higher temperatures than the others. Also, the upper end of the piston is made somewhat smaller than the lower end, to allow for expansion without binding. The only other way in which leakage from the combustion chamber might occur is through a crack in the cylinder wall or the piston. A defect of this kind would at once become apparent. If a leak of any kind develops, it is possible to continue the operation of the engine temporarily by increasing the pressure of the air by which the fuel is injected into the cylinder; but this is an inefficient way of operating, and should be adopted only in an emergency, and then only for a short time.

116. Cooling Water.—The Diesel engine demands a continuous flow of cooling water through the jackets; hence, care must be taken to keep the circulating pump going. If the water is discharged from each cylinder jacket through an open pipe, it is easy to determine whether each cylinder is being properly cooled; but if the circulating system is closed, a thermometer should be inserted into a suitable well screwed into the discharge pipe near the jacket. The temperature of the jacket water should not be much above 120° F. at the outlet. If the temperature is allowed to rise to 140° F. or more, there

is a probability that scale will be deposited in the jacket, which will retard the cooling and may lead eventually to overheating of the cylinder. The amount of cooling water required per brake horsepower per hour varies from 2 to 4 gallons, depending on the temperature of the ingoing water and the degree to which the engine is loaded. An average of 3 gallons per brake horsepower per hour may be assumed for ordinary conditions of running.

117. Fuel Pump.—Ordinarily the suction valve of the fuel pump consists of a head fastened to a stem that works through a gland and a stuffingbox. The valve is seated by the pressure of a light spring. The gland should not be drawn up so tightly, therefore, as to prevent the spring from seating the valve. It is better to allow slight leakage of fuel past the stem than to set up the packing so as to prevent the valve from seating. The plunger of the pump should be repacked whenever this becomes necessary. If the plunger is scored, it should first be trued up, either in the lathe or by the use of emery cloth, before being repacked. Tightening up the packing on a scored plunger will not stop the leaking and will increase the scoring. As the pump, under the control of the governor, regulates the amount of fuel sent to the cylinder, any wear of the levers and pins of the pump will affect the quantity of fuel discharged and to that extent will affect the power and speed of the engine.

118. Fuel Oil.—The fuel oil used in Diesel engines should not contain water in excess of about one-third of one per cent.; for, water decreases the efficiency and when mixed with the oil is bought at the same rate as oil. There should not be more than $1\frac{1}{2}$ per cent. of sulphur in the oil, because the fumes of sulphur combined with the water vapor produced during combustion will corrode the exhaust valve and its seat and the metal of the exhaust pipe. There should be very little incombustible matter in the oil, because such solid matter will increase the wear between the piston and the cylinder. The suction pipe from the fuel-storage tank should be fitted with a strainer, to prevent dirt from being drawn in; for, dirt in the atomizer or on the seat of the fuel-inlet valve will cause trouble

in the operation of the engine. The suction pipe should not reach to the bottom of the storage tank, because it would pick up any water that settled to the bottom of the tank. It is a good plan from time to time to test for water in the bottom. If water is found it should be pumped out.

119. Compressed Air.—The pressure of the air delivered by the compressor may be regulated by a valve on the suction pipe of the compressor. It is customary to use three storage vessels for air, one to contain the air for fuel injection and two to act as starting vessels. The reason for using two starting vessels is that one may act as a reserve in case of accident to the other. It is well to charge the starting vessels once a week; for a leak may develop and a vessel may be empty just when it is most needed. Moisture due to the condensation of vapor in the compressed air should be removed from the air receivers at frequent intervals. Fresh oil only should be used in lubricating the compressor. Filtered oil that has been used on the engine should not be used in the compressor, because it will carry with it some of the fuel oil, and this has been known to vaporize under the heat of compression in the compressor and cause irregular ignition in the engine. The air intake to the compressor should be fitted with a cloth filter, to prevent dust from entering, as dust will cause trouble in the fuel-inlet valve.

120. Fuel Atomizer.—The fuel atomizer should be taken out and cleaned at least once in three months, and oftener than that if the fuel valve acts erratically and seems to be clogged. The parts of the atomizer should be washed in kerosene and the oil holes and channels should be cleaned with a toothbrush dipped in kerosene. A clogged atomizer will reduce the power and speed of the engine, because insufficient fuel will enter the cylinder. A similar effect is produced, particularly under heavy load, by too much clearance between the needle-valve lever and the tappet against which it works in lifting the valve. The space between them should be no more than enough to allow daylight to be seen through it. It is advisable to have one or more extra fuel atomizers on hand,

so that, in case of failure of the one in use, another may be quickly substituted. The one that is removed may then be cleaned or repaired at leisure. Smooth and economical running of the engine depends on the proper operation of the fuel atomizer, and, as stated before, it should be removed and tested whenever an irregularity in the running of the engine is noticed.

MANAGEMENT OF GAS TRACTORS

OPERATION AND CARE OF TRACTORS

STARTING, STOPPING, AND RUNNING

STARTING

1. It is not to be expected that any one set of rules or directions will be sufficiently broad to include the operation of all makes of gas tractors, for the reason that tractors differ considerably in construction and in the arrangement of parts. Some are of the wheel type, while others are of the caterpillar, or crawler, type, and the methods of managing these two classes are different. Some have two speeds forwards and others have three, with the result that the controls differ somewhat. In other respects, however, all tractors have points of similarity. Each has an engine of one or more cylinders, operated on some form of liquid fuel, and the method of operating the engine is fundamentally the same in all cases. In this Section, therefore, the aim will be to describe, as far as possible, the operations that are common to all tractors, together with specific instructions for types to which the general rules will not apply.

2. Getting Ready.—Before the engine of a tractor is started, the operator should see that the whole machine is in proper condition for running. This means, first of all, that the fuel tanks should be filled. Tractors that use kerosene for

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regular operation have auxiliary tanks for gasoline, which is used in starting. Care should be taken, therefore, to have both the gasoline and the kerosene tanks supplied with ample quantities of fuel. The cooling system should next receive attention. If oil is used for cooling, the jackets, radiator, and pipes will contain the necessary supply of oil, which comes with the tractor; but in case water is used, the system will need to be filled with water. The filling funnel is usually located at the top of the radiator. Wherever possible, soft water should be used, as hard water will deposit scale on the inner surfaces of the jackets and the radiator. The oil cups should be filled with oil of the brands that the manufacturers recommend, and if force-feed oiling is employed, the oil container should be filled. In case the splash system of lubrication is used, the crank-case should be filled to the proper level with oil.

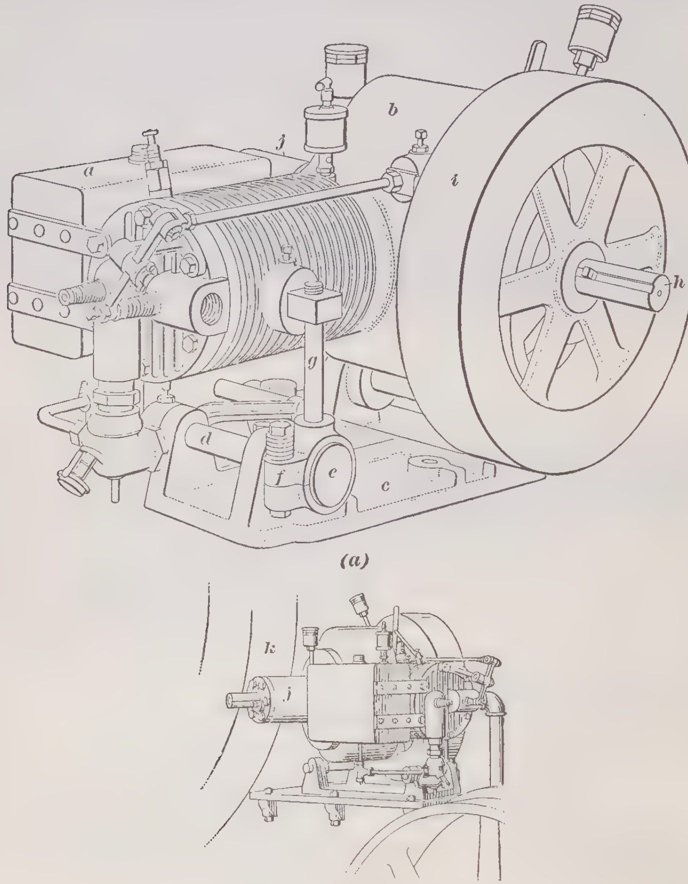
3. The engine cannot run without fuel; consequently, care should be taken to see that the fuel has free flow from the tank to the carbureter. To insure an ample supply of fuel for starting, it is advisable to flood the carbureter, and to open the needle valve wide. If there is insufficient fuel in the carbureter, or if the needle valve is too nearly closed, the starting of the engine will be followed by two or three puffs and then the engine will stop. If belts are used to drive the circulating pump and the fan, they should be tight. A slipping belt on the fan may not cause any particular difficulty, but if the pump is not driven, there will be no water circulation, and the engine will run hot.

Since the tractor is started by letting in the clutch after the engine has been set in motion, the various parts of the tractor should be ready for operation. The lubrication is a particularly essential point to be observed; hence, the various bearings should be oiled, or, in case grease is used, the grease cups should be screwed down so that the bearings will be well supplied with lubricant. If the tractor is a new one, the bearings will be stiff and will therefore require more oil than will be needed later, when the surfaces have run for a time and have worn to a smooth running fit.

4. The operator should be absolutely sure that he understands the construction of the tractor and the method of control. He should particularly be familiar with the purpose and use of each lever, because these are used to operate the clutches, the speed-change gearing, the reverse, the throttle, and the spark timing. Every manufacturer issues a booklet of instructions for the operation of his make of tractor, and the operator should study these instructions carefully before attempting to take charge of the tractor. The engine must never be started with the main clutch engaged; hence, the clutch should be disengaged and the lever set in the neutral position before the engine is started. This will allow the engine to run free until it comes up to normal speed, after which the load may be thrown on. Ignition is usually accomplished by battery while starting, and by magneto for regular running. The switch should therefore be thrown to the battery position. The spark lever should be set so that the spark is retarded as much as possible, and the compression relief cocks on the cylinders should be opened. Relieving the compression by opening these cocks will enable the engine to be cranked easily. The engine is then ready to be started.

5. Starting the Engine.—On small and medium-sized tractors, starting is done by grasping the flywheel and turning it in the direction in which it is to run, giving it a quick spin just at the moment the piston reaches the end of the compression stroke. Under normal conditions, if all parts are in proper working order, the engine will start promptly when the flywheel is rotated, or when the engine is cranked. As soon as it is turning over steadily, the compression relief cocks should be closed and the switch thrown over so that the magneto is cut into the ignition circuit and the battery cut out. Then the spark-control lever should be adjusted so as to advance the spark as the speed of the engine increases. If the engine is slow in gaining speed, the trouble is probably due to too much fuel; hence, the needle valve on the carbureter should be screwed in a little. In case the engine backfires on starting, the carbureter should be adjusted so as to admit more fuel.

6. As soon as the engine picks up speed, the throttle lever should be set in such a position as to cut down the amount of fuel admitted and so prevent the engine from racing. After it has been running for a short time, and all the parts have become



(a)

(b)

FIG. 1

heated to the working temperature, the fuel can be changed from gasoline to kerosene. First, the valve in the kerosene supply pipe is opened, allowing kerosene to flow to the carbureter, and then the valve in the gasoline supply pipe is closed.

When the engine operates on kerosene, water must be admitted with the fuel to prevent pounding. In order to regulate the amount of water, the regulating valve should be opened a little at a time, with a pause after each change of adjustment, so as to determine the position at which pounding ceases. The valve should not be opened any farther than is necessary to produce quiet running. Too much water will cause the engine to misfire or to stop.

In case the engine is fitted with two carbureters, one for each kind of fuel, and both are connected to the intake manifold through a two-way valve, the change from gasoline to kerosene may be made by simply throwing the valve from one side to the other.

After the change of fuel has been made and the engine is running smoothly on kerosene, the tractor may be started.

7. Heavy tractors are sometimes fitted with small auxiliary engines by which the main engines may be started. An auxiliary engine of this kind is shown in Fig. 1 (*a*). It consists of a small gasoline engine of the air-cooled type, having its own fuel tank *a* and its own ignition system. The crank-case *b* is hinged to the base plate *c* so that the cylinder can be swung slightly up or down. This movement of the cylinder is obtained by moving a lever connected to an arm on the end of the shaft *d*, which carries at its end an eccentric *e*, thus rotating the eccentric. A strap *f* on the eccentric is connected to the cylinder by the rod *g*. When the eccentric is rotated, the rod *g* is pushed upwards and the end of the cylinder is raised slightly, and the flywheel end of the frame is swung forwards on its hinge. The shaft *h*, to which the flywheel *i* is keyed, carries at its farther end a friction pulley *j* about 4½ inches in diameter and 5 inches wide. The auxiliary engine is bolted to the frame of the tractor, as shown in Fig. 1 (*b*), so that the friction pulley *j* is close to the face of the main-engine flywheel *k*.

To start the main engine, therefore, the auxiliary engine is first started and allowed to run for a short time, to bring it up to speed. Then the lever that rotates the eccentric is moved, throwing the friction pulley against the flywheel of the main

engine. This rotates the main engine at a speed great enough to insure starting, after which the starting engine is thrown out of contact with the main flywheel. The starting engine may readily be removed from the tractor and used for driving various farm machines requiring only small power.

8. Starting the Engine in Cold Weather.—Because of the wide range of work to which it is adapted, the tractor is apt to be used in winter as well as in summer, and the starting of the engine in cold weather requires special precautions to be taken to insure success. Trouble in starting engines in cold weather is due to the slow rate at which the gasoline vaporizes in a freezing temperature. Consequently, it is necessary to use some means whereby the fuel can be vaporized rapidly during the starting of the engine. After it is once started, the heat developed by its operation will be sufficient to insure the continuous vaporization of the fuel. The most common way of starting the engine in cold weather is by priming the cylinders with gasoline. The compression relief cocks are made with small cups at their upper ends, and before the cocks are opened, each cup is poured full of gasoline. When the cocks are opened, the gasoline runs down into the cylinder and there vaporizes, forming an explosive mixture with the air in the cylinder. Then, when the flywheel is rotated and the mixture is compressed and ignited, the resulting explosion starts the engine running. Because of the fact that they are used for priming, the compression relief cocks are also known as priming cocks.

9. The average fuel sold under the name of gasoline is of such low grade that it will not vaporize readily in very cold weather; consequently, if the tractor is to be used considerably throughout the winter, it is well to purchase a gallon or two of high-grade gasoline to be used exclusively for priming the engine when starting. The high-grade fuel will vaporize much more easily than the ordinary grade. In case the temperature falls to zero or below, it is probable that even high-grade gasoline will not vaporize readily enough to enable the engine to be started by the ordinary priming method. To overcome this

difficulty, a few drops of ether may be mixed with the gasoline in the priming cups before the cocks are opened. The ether vaporizes much more rapidly than the gasoline, and so hastens the formation of an explosive gaseous mixture. Another way is to heat the priming cups with a flame until they are quite hot, and then fill them with gasoline. The gasoline will become warm from contact with the cups and when it is allowed to run down into the cylinders it will vaporize easily. A blow torch is a convenient device for heating the priming cups.

10. There are numerous other operations that have been tried and found to aid in starting the engine during cold weather. One of these is to inject a small quantity of gasoline into the air-intake pipe, where it vaporizes and is drawn in with the first charge of air taken into the cylinder. Heating the intake manifold with a blow torch will also aid in producing an explosive mixture, as the heat will cause the gasoline to vaporize more rapidly. The same effect may be produced by heating the carbureter bowl, thus raising the temperature of the fuel it contains. However, heating with a torch is regarded by many operators as a dangerous practice and it is not recommended. The heating may be accomplished by pouring hot water over the carbureter and intake manifold, but care must be taken so that no water will get into the air intake. The heat given to the fuel makes it vaporize quickly and easily when the flywheel is turned and air is drawn through the carbureter, and the heated manifold prevents the gas from being chilled too much on its way to the cylinder.

Another point to be taken into account in extremely cold weather is the effect of the low temperature on the dry battery, for dry cells will be practically dead if exposed to zero weather. To insure current for ignition, the cells should be kept indoors overnight, and put back in the box just before the engine is to be started.

11. Failure to Start.—The three essentials to the starting and continued running of a gasoline engine are an explosive mixture of gas and air in the cylinder, sufficient compression of the mixture, and an electric spark to cause ignition; conse-

quently, if an engine fails to start after the directions given for starting have been carried out, the trouble will probably be due to the absence of one or more of these three essentials. The first point is to make sure that there is a supply of fuel in the fuel tank, and then to see that it flows freely to the carbureter. Opening the drain cock at the bottom of the carbureter bowl or reservoir will quickly show whether the trouble is due to lack of fuel. To find out whether the fuel is getting into the cylinder, the compression cock should be opened and the flywheel rotated. If fuel vapor has been drawn in, it will be expelled through the open cock and can be observed as a whitish vapor, resembling steam. If no vapor appears, it is probable that the needle valve is closed or clogged, so that no fuel can pass from the carbureter to the cylinder; or, the air intake may be blocked or clogged, so that there is insufficient air in the charge to produce an explosive mixture. If the mixture is too rich in gas, it may be diluted by turning the flywheel, leaving the compression cock open, so that air is pumped in and out through the open cock.

12. If the engine is found to be getting both gas and air, then attention should be turned to the compression. To test for compression, the relief cocks should be closed and the flywheel turned over. If it turns with practically the same resistance during a complete revolution, the compression is faulty, due to leaky valves that allow the compressed charge to escape; but if the resistance increases rapidly as the piston approaches the end of its inward stroke, the trouble is not due to lack of compression. It then remains to be discovered whether the ignition apparatus is in proper working order. First of all, the switch should be examined, to see whether it is closed. If it is, the wire to the spark plug should be loosened and the bare end should be drawn over the threaded part of the plug or the engine head. If a bright spark is not produced, the wiring may be disconnected, or the battery run down, or there may be a short circuit somewhere in the system. A fouled spark plug will interfere with ignition, and so the sparking points should be examined and cleaned. In cold

weather, the spark plugs may become damp and so prevent ignition. For this reason, it is well to warm them thoroughly before attempting to start the engine in cold weather.

13. Starting the Tractor.—After the engine has been put in motion and is running smoothly, the transmission gears should be set to give the desired forward speed or reverse, as the case may be. The nature of the speed-change gearing on the tractor will govern the number of control levers, but the book of instructions sent with each machine will readily point out the purpose of each lever. When the gears have been shifted so as to give the desired direction and rate of travel, the engine throttle should be opened and the spark advanced, which will have the effect of speeding up the engine. Then the main-clutch lever should be moved slowly so as to engage the main clutch gradually. The clutch should not be thrown in by one quick movement of the lever, as this throws the load on the engine so suddenly that excessive strains are set up, and broken parts may result. If the tractor drives through sprocket wheels and chains, the clutch should be engaged slightly at first, until all the slack in the driving chains is taken up, and then the lever can be thrown into the position corresponding to full engagement of the clutch.

STOPPING

14. Stopping the Tractor.—If the tractor is hauling a load, it may be stopped by simply disengaging the main clutch. This will disconnect the engine from the transmission gearing and the resistance due to the load will stop the tractor. If the load is very light, or if there is no load, the foot brake may be applied as soon as the clutch is thrown out, so as to bring the tractor to a standstill. If the tractor is running down hill, the speed may be reduced by closing the throttle and retarding the spark, and if the tractor is to be stopped, the main clutch should be released and the brakes applied. These directions are applicable whether the tractor is moving forwards or backwards.

15. Stopping the Engine.—Stopping the tractor throws the load off the engine, and to prevent it from racing the throttle should be closed and the spark retarded. If the engine, as well as the tractor, is to be stopped, the compression relief cocks should be opened so as to blow out excess oil and carbon. Then the throttle should be closed and the spark fully retarded. The ignition switch should be set to the off position. If the stop is to be a long one, as, for example, overnight, the cocks in the fuel supply pipes should be closed. If the engine uses both gasoline and kerosene, it will be found advantageous to shut off the kerosene and run on gasoline just before the engine is stopped. In cold weather the water cup in the kerosene carbureter or mixing valve should be drained, and if there is any chance of freezing weather, the water should be completely drained from the radiator, jackets, and pipes. It is advisable, before leaving the engine, to examine the bearings of the crank and connecting-rod, to see whether they need tightening.

RUNNING

16. Speed of Travel.—Some tractors are made with transmission gearing that allows only one forward speed. The rate of travel of such a tractor, therefore, is fixed by the sizes of the gears, and the running becomes a simple matter, as the one forward speed is used for all the work of the tractor, such as hauling, plowing, seeding, and so on. In case the design is such as to give two speeds forwards, the tractor should do most of its work at the higher speed. For, if the tractor is working at its full speed forwards, and a hill is encountered, or a tough piece of soil, so that a greater pull is required at the drawbar, the gears can be shifted so as to bring the tractor to low speed forwards. Thus, with the low speed always available in this way, the engine can be made to overcome a heavy load in an emergency, without undue strain on the tractor. It should be remembered that the slower the speed of the tractor, the greater is the pull that the engine can exert; but unless the character of the work absolutely demands it, the engine should not be operated continuously with the gears in the low-speed

position, as there is danger of overloading it under these conditions.

17. Overloading.—Because a tractor is a machine of iron and steel, many a buyer has regarded it as a thing that has no limit to its endurance. This is a wrong idea, for there is a limit to the power of the tractor, just as well as to that of the horse. No draft animal can work at its utmost exertion for long periods without showing signs of fatigue from the unusual strain, and the same thing is true of the tractor. If an engine is overloaded to such a degree that it slows up, the bearings and the gearing are subjected to excessive strains and the wear and tear is increased. The result of continued overloading is that the working parts are worn rapidly and the life of the tractor is shortened. In addition, overloading is wasteful of fuel. A well-designed engine develops the greatest power per gallon of fuel when it is running at its normal speed. When it is forced to run slowly, due to overloading, the amount of fuel required to produce a horsepower is increased. Finally, no time is saved by overloading, because the speed of operation is reduced. In view of all these reasons, therefore, overloading should be avoided and the engine should be run at its normal speed whenever possible.

18. Changing Speeds.—When it becomes necessary to change the rate of travel of the tractor, the transmission gearing is shifted so as to produce the desired increase or decrease of speed. The point to be kept in mind in doing this is to disengage the main clutch before shifting the gears. The speed-change gears must *never* be shifted while the main clutch is engaged. Instead, the clutch should be released and the transmission gears allowed to come to rest before the shift is made. These precautions are necessary to prevent wear and possible breakage of the gears. If the gear-shifting lever is moved while the gears are in motion and the shafts are turning, the gear-teeth may be damaged or broken, or the jaw clutch may be battered. In any case, there will be unnecessary wear on the transmission, and this can be avoided by using a little care and forethought. The same precautions must be observed when

the tractor is to be reversed; that is, the main clutch must be released before the reverse lever is moved so as to shift the gears into reverse. On most, if not all, tractors there is some form of adjustment by which the speed of the engine may be varied either above or below the normal speed. This adjustment is usually applied to the governing mechanism of the engine.

19. Running Idle.—When the main clutch is disengaged, the load is thrown off the engine and it runs idle. In some classes of work it may be necessary to throw out the main clutch every now and then for short periods. While the engine is running idle, it is consuming fuel, and so, if the load is thrown off for several minutes, the engine should be stopped, in order to save fuel. If the engine uses kerosene as fuel, it should be switched over to gasoline before it is stopped, so that it can be started readily. If the load is removed only for a brief time and the engine is allowed to run, it may be necessary to reduce the supply of water fed with the kerosene. If this is not done, the water will accumulate in the cylinder while the motor runs idle, and when the load is thrown on again, the engine is liable to choke. It may even be necessary to switch back to gasoline for a while in order to get the engine into good running order again. The operator must use his judgment as to whether he will stop the engine or let it run, the decision being governed by the length of idle interval and the conditions of operation. In very cold weather it would probably be better to let the engine turn over idly.

20. Sticking in Soft Ground.—In spite of all reasonable care on the part of the operator, the tractor is liable at some time to get stuck in a soft spot. This is particularly apt to occur during the spring, when the frost is coming out of the ground; but a low spot in a field, or a bit of badly drained soil, may cause the trouble. Sticking in soft ground is not ordinarily due to the sinking of the wheels under the weight of the machine, but rather to the turning of the driving wheels without moving the tractor. The driving wheels must have a firm footing on which to grip before they can propel the tractor. A

stretch of soft earth or muddy ground does not offer such footing, and, as a result, the driving wheels slip. If the power is not shut off promptly, the continued turning of the wheels will dig holes in the ground, the cleats acting as scrapers, and the tractor will settle into the trenches thus made. If the operator is certain that the soft earth is shallow and that there is firm ground beneath, he may allow the wheels to cut through to solid footing and then be able to pull out; but the best thing to do when the driving wheels slip in soft ground and begin to dig holes is to stop the tractor at once, before it gets too deeply embedded.

21. If the tractor is stopped just as soon as it threatens to become stuck, the load may be unhitched and the tractor may then be able to travel forward under its own power, after which the load can be drawn across the soft spot by long chains or a cable. An inexperienced operator, when confronted with trouble of this sort, is apt to attempt to get out by alternately throwing in the forward and the reverse gearing, at the same time turning the guide wheels to the right and left. Unless there is firm ground a few inches below the surface, this procedure will only make matters worse; for, the deeper the holes dug by the slipping wheels, the greater will be the amount of labor required to get the tractor out. In extreme cases, the machine may get so deep that the frame rests on the surface of the ground. When this occurs, it is useless to try to make the machine pull itself out. The proper thing to do is to pry up the frame of the tractor far enough to allow planks or posts to be slipped under the driving wheels, so as to provide a footing and enable the frame to clear the ground. The earth should be scraped out from between the cleats, so that the wheels may have the best possible grip on the footing provided. Small stones thrown on top of the posts or planks will generally give the driving wheels a better grip.

22. If the tractor is fitted with a differential gear, it is not sufficient to provide a footing for one driving wheel, because, if one wheel grips well, the other will spin and dig a hole. Both driving wheels will require good footing if any progress

is to be made. If none of the methods mentioned serve to get the tractor out of the soft spot, other means should be tried. A heavy plank may be pushed under the wheel and a chain may be wrapped around the rim of the wheel and fastened to the forward end of the plank. When the wheel is driven, the chain will wind on the surface of the rim and the wheel will be forced to roll forwards on the plank. If one plank is not long enough to carry the tractor over the soft spot, the process may be repeated. Still another method is to fix a post in solid ground some distance in front of the tractor and to run a cable back from the post to one of the driving wheels, around the rim of which it should be fastened. When the tractor is started forwards, the cable will wind on the face of the rim and the whole machine will be drawn forwards.

23. Steering.—The steering of the wheel type of tractor is accomplished by turning the steering wheel, which is connected by suitable gearing to the axle of the front guiding wheel or wheels. If the tractor operator is familiar with steering an automobile, he will find the tractor much more sluggish in its response to rotation of the steering wheel. The tractor is heavy and moves slowly, even when running at its greatest speed, and so there is no necessity for a quick-acting steering gear. Turns or changes of direction in the operation of the tractor need not be sharp or sudden, and so the steering gear acts slowly.

If the tractor is of the caterpillar type with a front wheel, turning the front wheel will not guide the tractor unless the friction clutch driving the track on the inside of the turn is disengaged. If the turn is only slight, the clutch need not be thrown out completely, but may be eased off and allowed to slip until the turn is made. In turning at a corner, the driving clutch on the side toward which the turn is made should be disengaged first of all, and then the front wheel should be swung. As soon as the turn has been made, the front wheel should be swung back straight and the clutch of the track reengaged. In the crawler type of tractor that has no front wheel, turning is accomplished entirely by disengaging one clutch or the other.

24. An arrangement known as a self-steering device may be attached to the tractor when plowing is to be done, thus

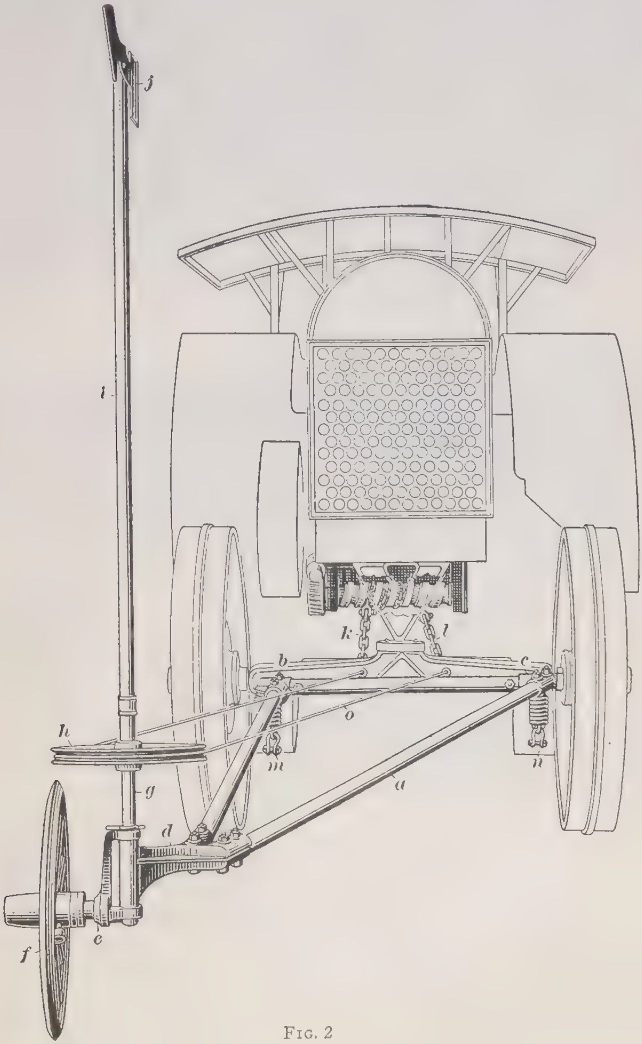


Fig. 2

enabling one man to operate both the tractor and the plows. One form of self-steering device is shown in Fig. 2. A triangular frame *a*, built up of piping and suitable fittings, is attached

to the front axle of the tractor by adjustable eyebolts *b* and *c*. At the front of the frame is a casting *d* on which is swiveled a knuckle *e* that carries the furrow wheel *f*. The post or pin *g* on which the knuckle swings carries the pilot wheel *h* and an upright tube *i* to which is fastened an arrow *j* that indicates to the operator the direction in which the furrow wheel is turned. The guiding chains *k* and *l* are disconnected from the clevises *m* and *n* by which they are ordinarily fastened to the front axle, and are attached to the ends of a wire cable *o* that passes through holes in the front axle and is drawn tightly around the pilot wheel *h*. The furrow wheel supports the front end of the frame and is made large enough to travel easily over rough ground.

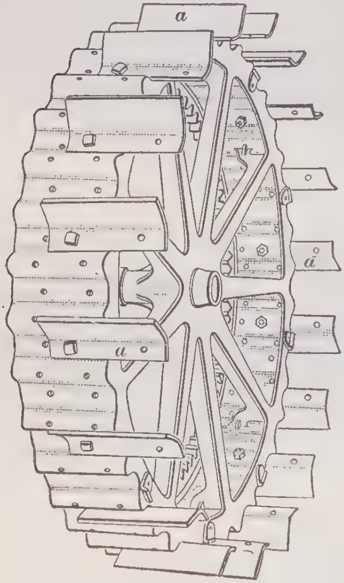


Fig. 3

25. When plowing with the self-steering device attached to the tractor, the furrow wheel *f*, Fig. 2, is dropped into the furrow. As the tractor moves forwards, this wheel hugs the land side, or vertical side, of the furrow and so holds the front axle square, thus compelling the tractor to follow the line of the furrow without any attention to the steering wheel on the part of the operator. At the end of the furrow, when the tractor is to be turned around, the steering wheel is used in the usual way. Turning the steering wheel pulls on the cable *o* in one direction or the other and so turns the pilot wheel. This movement swings the furrow wheel on the knuckle joint, with the result that this wheel moves in a curve, to one side or the other, thus swinging the front axle of the tractor and compelling it to follow. The distance at which the tractor runs from the edge of the furrow may be regulated by adjusting the eyebolts *b*

and *c*. Lengthening the eyebolt *c* and shortening the eyebolt *b* will make the tractor travel farther from the furrow and will increase the width of furrow made by the first plow. Reversing these adjustments will have the opposite effect.

26. Grouters and Wheel Extensions.—If the driving wheels of tractors were made with smooth rims, they would not grip on soft ground and there would be slip and loss of power. The rims are therefore fitted with lugs or grouters of various forms. They may be iron or steel castings, lengths of angle iron, or pieces of steel plate pressed into shape and bolted or riveted fast. When they are riveted in place, they are permanent, but the rims are frequently drilled with extra holes to enable additional grouters to be added when the tractor is to be used on exceptionally soft ground. A form of wheel constructed so that extra grouters may be attached is shown in Fig. 3. The wheel is a single steel casting having a corrugated rim, and holes in the rim enable the grouters *a* to be bolted fast, as shown. These not only give a better grip on the ground but also increase the surface in contact with the earth and so prevent the tractor from packing the ground tightly. It is claimed that the corrugated form of grouter or rim will pass over soft ground without tearing it up, while giving as good traction as other forms.

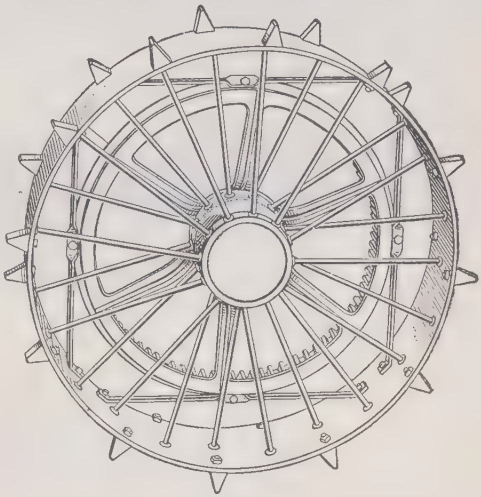


FIG. 4

27. Grouters are fastened at an angle across the rim in many cases, so as to reduce the jar on the tractor that would

result if they were set straight across; also, they are less likely to fill up with earth when they are set at an angle. Some driving wheels are fitted with spikes, as illustrated in Fig. 4, instead of long cleats. The shanks of these spikes are threaded and are inserted into holes in the rim, where they are held by nuts on the inside of the rim. They may be removed when the tractor is to be run over streets or surfaced roads that might be damaged by the spikes. If a heavy wheel-type tractor is to be used on soft ground, it may be necessary to increase the bearing surface of the wheels to prevent them from sinking into the earth. This object may be attained by fastening an extension rim to each wheel, as illustrated in Fig. 5, where the rim *a* is attached by bolts *b* to the edge of the driving wheel *c*.

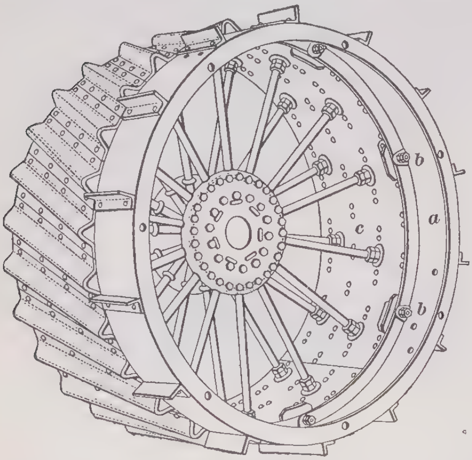


FIG. 5

CARE OF TRACTORS

28. Tractor Lubrication.—On most tractors, the oil for the cylinders and the bearings is supplied by means of a force-feed pump; consequently, even cold weather cannot stop the lubrication. The oil may become more sluggish under the effect of the low temperature, but the pressure due to the pump will cause it to flow. On the other hand, trouble is likely to be experienced if the oil is fed by gravity, as the cold weather may make the oil so sluggish that it will not flow under the pressure due to gravity. Such a difficulty may be overcome by using a special grade of oil for cold weather. This oil should be

lighter than the grade used in summer, and should not be affected seriously by low temperature. If the tractor uses chains for driving, these should be lubricated frequently with grease or heavy oil. The track of the caterpillar type of tractor is supplied with continuous lubrication. The teeth of gear-wheels should be lubricated with heavy oil or grease to reduce wear. Usually the instruction book for each make of tractor gives the kind of lubricant that should be used on each part and the frequency with which it is to be applied.

29. Tightening Nuts.—Because of wear, vibration, and shocks, the nuts used on various parts of the tractor are apt to come loose, and, if they are not tightened, to slack back and drop off. This may not result in immediate damage to the tractor, but there can be no doubt that looseness of parts that should be kept tight results in needless wear and may cause excessive strains, resulting in breakage of some part or parts. To keep the tractor working at its best, therefore, all nuts should be examined periodically, to see that the parts are in correct adjustment. Care should be taken not to draw up a nut too tightly, as there is danger of twisting off the bolt or stripping the threads. A long-handled wrench should not be used for tightening a nut on a bolt of small diameter. If two nuts are used together, one acting as a locknut, the outer one should always be loosened before any adjustments are made, and it should be tightened last. The two nuts should not be turned at the same time. In case a split pin or a cotter pin is used to hold a nut in place, it should be of the proper size. If it is too small, the nut may slack back and shear it off.

30. Adjusting Main Clutch.—The main clutch, when it is fully engaged, should be able to transmit the full power of the engine without slippage, and when the clutch lever is moved to the release position, the shoes of the clutch should not touch the friction surface. The construction of clutches varies in detail, but in principle all are much alike. The two parts of the clutch are engaged by forcing friction shoes outwards against the rim of the other part of the clutch. The arms that carry these shoes are adjustable as to length. So, when the

shoes have worn down to such an extent that they no longer grip the rim tightly, and are inclined to slip when fully engaged, the arms should be adjusted so as to take up the wear and make the shoes grip tightly. When this is done, care must be taken to see that the shoes do not touch the rim when the clutch lever is in the off-position. Furthermore, the shoes should be adjusted so that they bear with equal pressures.

31. Oil on Clutch.—The shoes of some forms of clutches are faced with wooden blocks, and if these are kept dry, they are apt to be worn rapidly, especially if the clutch is thrown in and out frequently. On the other hand, the life of the blocks will be lengthened and the action of the clutch will be much improved if a little oil is used on the rubbing surfaces. As already pointed out, the load should never be thrown on the tractor suddenly, as by jamming the clutch in quickly; instead, the clutch should be engaged gradually until the load is started. This means that the shoes must slip while the clutch is being thrown in, and if the blocks are dry, they are apt to seize and start the load with a jerk. On the other hand, if the surfaces are slightly oily, the engagement will be easy and smooth, and the blocks will not char and smoke when the clutch slips. Only a small amount of oil should be used, as an excessive amount will cause slip under full load, and so defeat the very purpose of the clutch.

32. Brake Adjustment.—The usual form of brake consists of a drum or pulley fixed to one of the shafts through which the tractor is driven, and surrounded by a brake band that can be tightened onto the surface of the drum. In other cases, a shoe or block is pressed against the brake drum to produce the friction required to give the necessary braking effect. The brake must be able to hold not only the tractor but also the load behind it. The accuracy of adjustment and action of the brake is therefore an important matter. The brake band is usually lined with some form of material adapted to resist heat and wear, and provision is made to enable all slackness due to wear to be taken up. The brake band should be adjusted, therefore, so that it will not rub on the brake drum

when the brake lever is released; otherwise, it will act as a drag on the engine and reduce the useful power. On the other hand, it should grip the drum tightly enough to hold the tractor and its load when the brake is put on full.

33. Cleaning Oil Strainer.—The force-feed oiling system commonly used on tractors includes a wire screen of fine mesh through which the oil is forced to pass and by which the larger particles of foreign matter are strained out. The ordinary work that a tractor is called upon to perform stirs up considerable dust, which, if not prevented from entering the oiling system, will clog the oil passages. The wire-gauze strainer that performs this cleaning of the oil must itself be cleaned periodically; otherwise, the accumulated dirt will clog the meshes and restrict the flow of oil, with the result that the bearings will not receive sufficient lubrication, the engine will tend to overheat, and there will be waste of power. When these symptoms are observed, the condition of the oil strainer should be examined. If it is clogged, it should be taken out and cleaned by washing it thoroughly in kerosene. If cleaning the strainer does not remedy the trouble, then the oil should be drained out, the system should be washed out with kerosene, and a supply of new oil should be put in.

34. Laying Up the Tractor.—Although the tractor has been developed to the point where it can be used the year around, it is usually laid up during the most severe months of the winter, when the small amount of work to be done does not warrant keeping it in service. When a tractor is thus laid up for a time, it should be run under cover, where it will be protected from the weather. The practice of leaving the tractor in the open, either wholly unprotected or covered only with a tarpaulin, is to be condemned, because the moisture will cause the parts to rust rapidly. All water must be drained from the cooling system, and the magneto and the batteries should be removed and placed in a dry place. To prevent internal rusting, the valves and pistons may be coated with thick oil poured into the cylinders and spread over the surfaces by turning the flywheel. All priming cocks should be closed,

and all bright parts should be coated with heavy oil to keep them from rusting. The fan belt and the governor belt should be loosened and covered with canvas so that they will not be affected by moisture.

35. Cooling Agents.—The cylinders of the engines used on gas tractors are jacketed and are cooled by the circulation of either water or oil. Water is the more usual cooling agent, because it is cheap and easily obtained; but it has a disadvantage in that it will freeze in winter weather, so that, to prevent cracking of the cylinders, the jackets and radiators must be drained if the tractor is allowed to stand idle during freezing weather. Freezing may be prevented by mixing alcohol, glycerine, or salt with the water, since these substances lower the freezing point of water. However, tractor operators often object to the use of anti-freezing solutions either because of the expense of the chemicals or because of the deposits left in the radiator when the water evaporates. The loss of water due to boiling and the escape of the steam makes it necessary to replenish the system with water at intervals. When oil is used as the cooling agent, there is practically no loss by evaporation, as the oil does not boil, and so there is no necessity for adding oil except to make up for waste due to leakage. Furthermore, the oil will not freeze, and so the engine may be allowed to stand idle in the coldest weather without draining the cooling system. A solution made by dissolving 5 pounds of calcium chloride in a gallon of water will not freeze until the temperature falls to about 35 degrees below zero. If glycerine is used, the solution should consist of equal parts of water and glycerine. Water that has dissolved all the common salt that it will hold, will not freeze above zero. Equal parts of alcohol and water form a solution that will remain fluid at 10 degrees below zero.

36. Care of Radiator.—The radiator of the tractor is apt to give trouble through clogging with dirt and sediment, which will result in sluggish circulation of the cooling water and an overheated engine. All water taken from wells or springs contains mineral substances that, under the effects of

heat, are deposited on the inside surfaces of the radiator and on the walls of the water-jacket and pipes. The effect of this incrustation is to reduce the rapidity with which the heat is transmitted from the cylinder to the water in the jacket and from the circulating water in the radiator to the cooling air. Rainwater contains no such impurities, and it is advisable, therefore, to use this kind of water in the cooling system. If the radiator and the jackets are badly coated with scale, they may be cleaned by filling the system with a solution composed of one part of hydrochloric acid to ten parts of water. This weak solution can be left in the system several hours, after which it should be drained out and the system should be thoroughly washed out with fresh water, so that no traces of acid remain.

37. Graphite, such as is used to remove scale from the interior of steam boilers, may be used to clean radiators and jackets. If graphite is mixed with the water first put into the system, it forms a sort of coating on the water surfaces of the radiator and jackets, and the scale and sediment are thereby prevented from adhering to the metal. If graphite is added after scale has been formed, it works its way into the cracks in the scale, gets underneath the scale, and thereby loosens it from the metal. This action is purely mechanical and cannot injure the metal in any way. A teaspoonful of graphite to a gallon of water will be found sufficient. Kerosene has also been used to loosen scale. The system is filled nearly full of water, and then a quantity of kerosene is poured in, after which the water is allowed to drain out slowly. The kerosene floats on the water, and as the water level descends the kerosene adheres to all the inside surfaces, where it works into cracks in the scale and loosens it in much the same way as does the graphite.

38. The radiator of the tractor is sometimes of the open type, consisting of a tower inside which the cooling water trickles down over screens and collects in a tank at the bottom, while the cooling air is forced upwards through the descending water. With a radiator of this type, much of the cooling of

the water is accomplished by evaporation; that is, part of the heated water is turned into vapor and is carried away by the air. The heat required to convert this water into vapor is taken from the hot water, which is thereby cooled. Because of this continuous loss of water by evaporation, the system must be refilled repeatedly. This type of radiator is open to the air, and as the surrounding atmosphere usually contains much dust raised by the tractor, this dust readily finds its way into the cooling system, making frequent cleanings necessary.

39. Cracked Water-Jacket.—If a water-jacket is cracked by the freezing of the water, and the damage is not too great, the jacket can probably be repaired by filling up the crack with a rust mixture composed of sal ammoniac and iron filings. The sal ammoniac crystals should be dissolved in a half-cupful of water until the solution becomes so strong that no more sal ammoniac will dissolve. Then some of this solution should be poured on a teaspoonful of fine iron filings, and the mixture should be worked into a thick paste. The paste should then be forced into the crack in the water-jacket by using a thin knife blade. When the crack has been filled in this way, it should be allowed to stand several days, during which time the sal ammoniac will act on the filings and rust them into a solid mass that will be rusted fast to the sides of the crack also. This kind of repair may not last permanently, but it will enable the engine to be used while a new cylinder is being shipped.

MANAGEMENT OF AUTOMOBILE ENGINES

CARE AND ADJUSTMENTS

INSPECTION, AND LOCATION OF FAULTS

GENERAL INSPECTION

1. The owner or chauffeur who for the first time takes charge of an automobile must, especially if the machine is of an unfamiliar type, make a careful examination of the condition of the automobile before it will be prudent or even safe for him to attempt its operation. This examination should not be limited to the engine and its accessories, but should include all parts of the car. In the following articles, attention is directed to the parts of the engine that should receive careful attention.

2. In the first place, a general survey of the engine should be made, special attention being given to the location and mode of action of each individual part included in the valve mechanism, the ignition mechanism, and the radiator, carbureter, etc. Attention should be given to the method of lubrication of the various parts, and the location of the oil filling pipes, the location of all grease cups, the method of supplying fuel to the carbureter, and other points that can be ascertained without the removal of any of the parts. On completing this preliminary investigation, the condition of the various parts should be examined in detail.

CARBURETERS

3. After the main gasoline valve between the carbureter and the tank has been opened, the carbureter should be examined for leaks. If gasoline drips, it may be because the gasoline connection to the carbureter is not tight enough, and it can be stopped by giving the nut another turn or two. If the drip comes from the carbureter bowl it is very likely to be caused by an imperfect seating of the needle valve. Whatever steps are necessary to expose the top of this valve should be taken, and then the top of the valve tapped very gently with a light hammer. Usually this will bring the valve to a good seat and stop the leakage. In some very rare cases, it may be necessary to grind the valve to its seat. To do this, flour of emery, powdered pumice, or some similar abrasive is mixed with oil or water, and placed between the valve and its seat; then the valve is turned one way and then another through part of a revolution, until it seats properly. When the point of the valve is badly worn, it is a good plan to have it turned to a good taper in a machine shop.

If the proper seating of the needle valve fails to stop the gasoline drip, there is a likelihood that the leak is caused by a defective float.

4. When a cork float is used in the carbureter, it may become saturated with gasoline, or logy, as it is usually called, and should be removed from the carbureter and thoroughly dried. When all gasoline has been driven off and the float is perfectly dry, it should be rendered impenetrable to gasoline by varnishing it with shellac and allowing the shellac to dry for about 24 hours. When the cork float is gasoline-soaked it will not rise high enough to cut off the gasoline entering the carbureter, and flooding is the result.

5. Flooding also results if a metallic float has become leaky; for gasoline enters the float, destroys its buoyancy, and causes the needle valve to be held off its seat. The presence of gasoline can be revealed by shaking the float when it is removed from the carbureter. A swishing noise will indicate a

partly filled float. A float that is full or almost full is indicated at once by its increased weight.

The location of the leak can often be determined by a careful inspection of the entire surface of the float. In some cases, however, the leak is very minute, and it may become necessary to immerse the float in hot water in order to vaporize the gasoline that it contains; bubbles due to the escape of gasoline vapor will then disclose the location of the leak.

Before attempting to repair the leak by soldering, great care must be taken to remove any gasoline or water that the float may contain, by heating it so as to evaporate the gasoline, if necessary. In case the float contains water, a small hole through which the water can trickle out may have to be punched into the float, and subsequently closed by soldering. In soldering the leak, as little solder as possible should be used, in order not to change the buoyancy of the float to an appreciable extent.

6. If a float is set too high with reference to the float-valve seat, it will not close the float valve before gasoline escapes from the spray nozzle. In such cases, the carbureter drips when the main gasoline valve is opened. When trouble is experienced from a float that is too high, a metallic float will be found empty and a cork float not gasoline-soaked.

If a float is set too low with reference to the float-valve seat, the float will close the float valve when the gasoline level is still some distance below the orifice of the spray nozzle. The symptoms of trouble produced by a low float adjustment are a weak mixture at slow speed and probably difficulty in starting the engine, owing to the fact that considerable suction is required to lift the gasoline to the mouth of the spray nozzle.

When a float leaks and proper steps cannot be taken immediately to remedy it, the car should not be left standing with the main gasoline valve open, because of the danger of fire resulting from the accidental ignition of the dripping gasoline. When a pressure system is employed for forcing the gasoline from the tank to the carbureter, the drip can be ended by turning the three-way cock on the pump to its "vent" position.

7. No adjustments should be made on the carbureter until the trouble is traced, beyond any doubt, to that source, and then they should be made only by an experienced man. Adjustments are usually provided on the carbureter, and when there is any doubt concerning these, the printed instructions of the manufacturer should be followed carefully. A copy of instructions should be found in each new car. A fairly accurate adjustment can be effected by running the engine idle, and noting its action under different throttle openings. When an approximate adjustment is obtained in this way, the car must be run under different road conditions, and corrections made in the mixture to produce the best results at all times.

8. Next to making sure that there are no gasoline leaks, the most important thing is to see that no bearings are too tight or have seized, owing to lack of oil or the bending of the crank-shaft or connecting-rods. The priming cocks should be opened and the shaft turned over slowly by hand. The shaft should move with entire freedom, a little more easily at the beginning and end of the piston stroke than at mid-stroke, because of the slower movement of the piston at the ends of the stroke, but with no binding or sticking at any point. If the shaft turns hard, the car should be taken to the repair shop, since probably either the bearings or the pistons are cut, or the shaft or rods are sprung out of true, as, for example, from having struck a loose nut or other obstruction in the crank-case, or from preignition in the cylinders. Fortunately, serious trouble of this sort does not often occur.

9. At the outset, it is well to locate all loose bearings. If they are very loose, there is a strong likelihood that they have been cut, in which case they ought to be opened, scraped, and refitted at the earliest possible moment. Of the main-shaft bearings, the one next to the flywheel is the most likely to be loose. A jack may be put under the flywheel and the jack-lever worked gently up and down to disclose looseness, if any, in this bearing.

To expose the crankpin bearings of a motor it is generally necessary to take down the bottom half of the crank-case,

which is generally attached to the upper half by capscrews or studs, and which simply serves the purpose of an oil pan. Under this arrangement, the shaft bearings are usually supported from the upper half of the crank-case, which is itself supported on the frame of the car. Nevertheless, it is advisable, when slackening the screws or the nuts on the studs, to find out whether or not they are carrying the weight of the crank-shaft. This can be done by slackening all the screws several turns, and then pushing upwards against the oil pan with the hand to see how much pressure is necessary to lift the pan off the screws. If the shaft is found to be resting on them, it will be better not to take it down at once, unless it is evident that the main-shaft bearings themselves need attention. Generally, if the shaft is supported by the bottom half of the case, the crankpin bearings can be reached from handholes located in the bottom or sides of the crank-case.

10. The crankpin bearings can be tested for tightness by setting the engine at mid-stroke and oscillating the flywheel very gently back and forth while the fingers of one hand are resting on the edge of the crankpin bearing. A slight looseness may be allowed, provided the lubrication is sufficient and there is no cause to suspect that the bearings have been cut. The amount of permissible looseness will depend to a great extent on the particular engine and the speed at which it is to run. A vertical four-cylinder engine running at moderate speed will bear as much as .002 inch of lost motion on the crankpins, but if the same engine is run at a high speed this will be too much.

11. The main-shaft bearings will bear less lost motion than the crankpin bearing and if one main-shaft bearing is worn more than another, as is likely to be the case, it will result in one-sided wear of the crankpin bearings, due to the settling of the shaft. The main-shaft bearings ought not to have more than .001 inch of play before being taken up, but more than this is often found.

A double-opposed horizontal engine, no longer used in automobiles, will, sooner than any other type, develop a pounding

sound, generally called a *pound,* at the main-shaft bearings, owing to the fact that the explosions occur alternately in opposite cylinders, and there is nothing to keep the shaft against one or the other side of its bearings.

12. In addition to the inspection for loose bearings, the principal nuts and screws should be tested to see that they are tight, and if any cotter pins or lock washers are missing from bolts, studs, or slotted nuts, they should be supplied at once. The bolts on the crankpin bearings should also be examined for tightness, and to see that cotter pins or locking wires are in place.

VALVES

13. The only types of valves in use at the present time are the mechanical poppet valve and the sliding-sleeve valve. The sliding-sleeve valve has a positive action, due to an eccentric drive, and is subject to very little wear from either friction or the action of the hot gases. The valve will therefore require very little attention other than the proper lubrication. Lost motion in the eccentric straps should be taken up before it becomes excessive.

The poppet valve, on the other hand, is opened by cam action and closed by a spring. The force of the blow struck, as the valve comes to its seat, together with the action of the hot gases, causes both wear and distortion of the valves, especially of the exhaust valve, and makes it necessary frequently to grind the valve to a bearing on its seat. This constant grinding will eventually lower the push rod to a point where it will not have enough clearance above the cam, and the proper adjustment must then be made by means of the adjusting nut.

LUBRICATION

14. The user of a car should satisfy himself regarding the lubrication of every part of the engine. Every oil pipe should be traced, and every oil cup and oil hole located and the purpose of each ascertained. Oil pipes leading from the oil pump

should be disconnected close to the bearings or cylinders, and the pump worked by hand, when possible, to see that it is feeding properly. If oil does not come from a pipe, the pipe should be disconnected close to the pump; and if no oil comes from the pump at the point of connection, the stoppage should be traced through the pump until the point of stoppage is located. The trouble will probably be found to be caused by dirt or waste under the check-valves of the pump, or air leaks in the suction pipe. If oil comes from the pump when the pipe is disconnected, the latter is stopped up, and can be cleaned by running a wire through it. Generally, however, any obstruction of this sort will travel to the end of the pipe and lodge in the check-valve, if there is one at that point, and hence the check-valve should be examined and cleaned if necessary.

15. When a circulating constant-level splash system is used there is no need to regulate the amount of discharge from the pump, as an excess of oil is being pumped at all times. The excess overflows the oil troughs in the crank-case and returns to the main reservoir. This system uses the same oil over and over, thus causing a deposit to form at the bottom of the well. As this tends to thicken the oil and make it sluggish, it is necessary at short intervals to withdraw the old oil, clean out the well and supply the necessary amount of clean oil.

16. With the non-circulating constant-level splash system, only enough oil is pumped from the well to compensate for that used, and therefore the supply must be regulated, the general method being to place a relief valve between the pump and the point of discharge. A compensating device must also be used in order to equalize the distribution of the oil in order that each trough may receive its proper supply. As there is no oil returned to the well the supply is always clean and the well seldom needs cleaning.

17. In the high-pressure lubricating system the pressure must be kept just below the point at which the engine will smoke, and this will require very careful adjustment. Here again the relief valve may be used. With this system the oil is

forced through the length of the crank-shaft, holes being drilled for this purpose when the crank-shaft is made, and at each crank bearing radial holes are drilled by means of which the oil is conveyed from the center of the crank-shaft to the bearing surfaces. The main bearings, however, are generally lubricated by tubes leading directly from the pump to the bearings.

18. In lubricating systems requiring a circulating pump, the oil is forced through the system by means of either a gear pump or a pump having a single plunger of sufficient size to supply the entire system. In either case the oil pumped must be considerably in excess of the maximum quantity needed, and some method must be adopted to regulate the amount of oil that reaches the point of discharge. This is generally done by placing a relief valve at the discharge side of the pump. This valve is then connected to the suction side of the pump so that the overflow is in constant circulation.

19. The manner in which oil is supplied to the crankpins should be ascertained, since these are sometimes fed simply by internal splash and sometimes by centrifugal ring oilers and oil passages drilled through the cranks. If internal splash is relied on, the user should see that the crank-case contains enough clean oil to allow the connecting-rod caps to dip into it about ½ inch at the lower end of their stroke.

If the car has not been used for a considerable time, the oil in the crank-case, oil cups, and reservoir is likely to be stiff and gummy. If this is the case, the oil should be drawn off, and a moderate quantity of kerosene used to make sure that the oiling system generally is thoroughly clean. Before starting the motor, a liberal supply of fresh oil should be provided, as the kerosene will cut away the old oil wherever it reaches, and the pistons, cylinders, and bearings might become cut before the fresh oil can reach them from the reservoir. When oil has not been cleaned out in this manner, it is a good precaution, on general principles, to put a pint or a quart of fresh oil into the crank-case. If, however, on starting the motor it is seen that a considerable quantity of white smoke is being produced, the

crank-case has evidently too much oil, and a portion should be drawn off.

Gasoline should not be used for cleaning out the old oil, as it leaves the parts perfectly dry. Kerosene, on the other hand, will leave a slight coating which will tend to keep the parts lubricated until the fresh oil works into the bearings.

IGNITION

20. The ignition circuit should next be gone over. This should be done with the ignition switched on, the gasoline shut off, and priming cocks (if any) open. In some cases, a quarter-turn of the key in the ignition switch is required to close the ignition circuit, and, in others, a half-turn of the key is required. A good rule is to try the key after turning it. If it cannot be withdrawn from the switch the current is "on"; when it can be removed from the switch, the current is "off." The positions of the lever controlling the spark for early and late ignition should be ascertained by a careful examination of the timer, and the lever should be set for a late, or retarded, spark, as a precaution in case of any accidental explosion in the cylinders. If the car is equipped with individual coils, as is the case of the Ford car, the engine should be turned over slowly, and the sound of each of the vibrators on the coils noted. The sound should be clear and regular, and fairly high without being tinny. If necessary, the contact screws, or the tension screws, if there are any, of the vibrator springs should be adjusted until the vibrators sound alike.

21. The timer should be examined to see that the contact segments are not badly pitted by the spark at the leaving edge. If they are pitted, or if the fiber or hard rubber adjacent to them is roughened by the sparking, the timer should be cleaned up as well as possible with a piece of sandpaper or a file, and the first opportunity taken to true it in a lathe. If the timer is rough, the contact roller or fingers will jump and give very erratic contact when the motor is running fast.

When a magneto or timer-distributor is used as a source of current, the contact points must be kept clean, flat, and parallel,

and adjusted, when necessary, by a special wrench and gauge supplied for that purpose.

22. The spark plugs should be unscrewed and their condition examined. It is not necessary to take them apart unless they need cleaning, or unless it is discovered that the porcelain is broken, which will sometimes be indicated by a looseness of the outer end. If the porcelain is broken and there are spare porcelains at hand, the bushing may be unscrewed and a new porcelain and gasket inserted. Usually, it is impracticable to use the old gasket a second time, as the bushing has to be screwed down so tight as to endanger the porcelain. The bushings should be set down sufficiently to prevent leakage past the porcelain, but no more. The construction of many makes of spark plugs will not permit of their being taken apart, and the only remedy for a defective plug in such cases is the substitution of a new one.

23. The gap between the spark points should not be greater than $\frac{1}{32}$ inch, nor less than $\frac{1}{64}$ inch. The points should be kept true and square, as the spark will not be so intense if it jumps between needle points. Soot or carbon may collect on the part of the spark plug inside of the cylinder, which will short-circuit the high-tension current and stop sparking of the plug. When possible, the plug should be taken apart, and the porcelains cleaned with a cloth or brush wet in gasoline.

24. Spark plugs with porcelain cores can be cleaned very thoroughly, without taking them apart, by placing them in an iron vessel in boiling water in which caustic soda, sold for household use under the name of *lye*, has been dissolved in the proportion of 1 pound of lye to 1 gallon of water. The water is kept boiling for about 30 minutes, and the spark plugs are then washed in several changes of clean water. When they are dry, any carbon remaining on the core or shell can be easily brushed off. Care should be taken that the spark points are restored in their correct relation to each other when the plug is ready for service. This may be accomplished most easily by assembling the plug and then bending the points till they assume their correct relation to each other.

25. The battery may be weak and may have to be recharged or replaced. If dry cells are used, it is likely that some of them are weaker than others. The only way to determine this is to use a battery tester, which is a small pocket ammeter through which the cell may be momentarily short-circuited. It is poor practice to try to raise the strength of a battery which is nearly run down by replacing one or two of the cells with new ones, as these new cells will quickly discharge themselves to the same point the others have reached. The battery as a whole may be tested by disconnecting one of the secondary cables from the spark plug and noting the length of the spark in the open air. The spark should be at least $\frac{3}{8}$ inch in length—$\frac{1}{2}$ inch is better. The coil should not be worked with the detached cable held so far from the motor that no spark can jump, as this is liable to tax the insulation of the secondary winding.

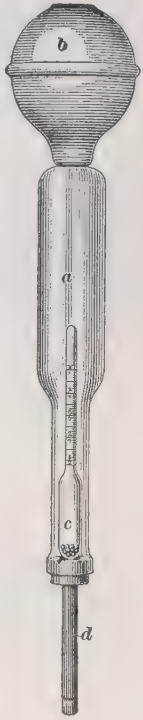


Fig. 1

26. Storage batteries of the lead-plate type can be tested either with a voltmeter or with a hydrometer, the hydrometer test being preferable. If a voltmeter test is made, the testing must be done while the battery is discharging current; if the test is made while the battery is idle, a high voltage may be shown, apparently indicating that the battery is well charged, when in reality it is practically discharged. The test should be made with the engine running, or the lights turned on if the storage battery is also used for lighting. A fully charged storage battery should register as high as 2.5 volts per cell upon completion of the charging. A voltage of 1.7 per cell shows that the battery is practically discharged, and needs recharging. A hydrometer test is made by means of a *hydrometer syringe*, one form of which is shown in Fig. 1. This consists of a glass tube *a*, to one end of which is fitted a soft-rubber bulb *b*. The tube contains a hydrometer *c* constructed for liquids heavier

than water; its stem is graduated to give the specific gravity of the liquid being tested, instead of the arbitrary Baumé readings. Some hydrometers suitable for testing storage batteries are graduated with both the specific gravity and the Baumé scale. The other end of the tube *a* is closed by a soft-rubber plug containing a hard-rubber tube *d* in its center. By taking out the pipe *d* and the plug, the hydrometer can be removed from the syringe. Since the hydrometer is a very fragile instrument, it must be handled carefully.

To make a hydrometer test, the rubber bulb of the syringe is compressed and the pipe *d* is inserted through the vent tube of each cell of the battery. The pressure on the bulb is then gradually released while the syringe is held vertical, until enough electrolyte has been drawn up to float the hydrometer. The reading is then taken at the surface of the electrolyte. No reading should be taken while the hydrometer is touching the wall of the syringe, as will occur if the syringe is not held vertical.

A fully charged lead-plate storage battery will show a specific gravity of the electrolyte from 1.275 to 1.300. When the specific gravity is as low as 1.150, the battery is practically discharged, and should be recharged at once.

ENGINE CONDITIONS WHEN RUNNING

27. When the engine has been gone over carefully, it may be started, to determine whether the ignition and carbureter adjustments have been made properly. Set the throttle so that the motor does not run excessively fast, and listen to the sounds it makes. Any knocking sound coming from the engine should at once be traced to its source and eliminated. Should the knock be found in the loose coupling between the clutch and the gear-shaft it will not give trouble, as this coupling is intended to be loose. Any knock due to a loose bearing or a loose bolt, however, should at once receive attention. It may be found that the motor will run light—that is, without driving the car—and with the throttle nearly closed without developing a knock, but may knock badly when under load.

28. The sound of the impulses should be listened to; also the sound of the exhaust at the muffler. If the engine has several cylinders, the impulses should be equally timed and should be of equal force. If, with the spark somewhat retarded, the impulse is more energetic in one cylinder than another, which may generally be told by the muffled sound of the explosion, it is either because ignition takes place too early in the cylinder or because a deposit of carbon in the combustion chamber ignites the charge in its own vicinity immediately after the spark, so that the charge is burning from two points at once and consequently more rapidly than it should. Actual preignition, that is, too early ignition, due to carbon deposit, seldom occurs when the engine is running light, but may occur when the engine is driving the car.

If early ignition in one cylinder is due to faulty timer adjustment, the difficulty may be corrected in some one of several ways, according to the construction of the circuit-breaking mechanism. Sometimes the adjustment must be made by filing the contact segments. This should, however, be attempted only as a last resort, after it has become evident that the trouble is not caused by heated carbon in the cylinder or causes that can be corrected in some other way.

29. When the engine is running light, a late ignition in one cylinder will show itself by a louder exhaust from that particular cylinder, owing to the slower combustion of the charge, and consequent higher pressure when the exhaust valve opens. The remedy for late ignition is practically the same as for early ignition, any adjustment of the circuit-breaker being, of course, in the opposite direction.

SPARK TIMING

30. When a car is equipped with a timer and vibrator system, a quick method of testing the spark timing is as follows: Shut off the gasoline, retard the spark as far as possible, and open the priming cocks. Turn the crank slowly by hand, letting the air escape through the cocks so that the compression will not cause the pistons to run ahead, which would take up

the slack between the crank-shaft and the timer, thus giving a false result. Note the position when the vibrator begins to buzz, and mark the rim with chalk or otherwise. Now turn the crank, *always forwards,* until the next vibrator begins to work, and note the flywheel position again. If the engine has four cylinders, the new position should be exactly one-half a turn from the old. Practically all modern cars have the flywheel rims already marked to indicate the top and bottom positions of the cranks, and these marks may be used, as the spark should occur exactly at the outer, or upper, dead center when fully retarded.

31. The setting of the circuit-breaker mechanism of a timer-distributor must be done with the distributor head removed, and consequently there is no high-tension current available. The piston of cylinder 1 is placed on its compression dead center by the flywheel marks and the spark-control lever is slightly advanced from its fully retarded position. If the induction coil has a vibrator, or if a separate magnetic relay is used, which either has a vibrator or can be changed over at will to give shower sparks or single synchronized sparks, the shower-spark ignition is switched on and the cam of the timer is slowly turned in the direction in which it normally rotates until the vibrator begins to buzz. The cam is then fastened to its shaft. If the ignition system only delivers single sychronized sparks, the ignition does not need to be switched on; the timer cam is slowly rotated until the contact points in the timer just begin to separate, when the cam is fastened to its shaft.

Under no consideration should the timing of a timer-distributor be undertaken before the contact points have been adjusted to separate the proper distance.

32. The first step in setting a magneto, after it has been fastened to its seat, is to adjust the control rod or rods so that the spark-control lever in moving through its whole range of motion will also move the spark-advance and retard mechanism of the magneto through its whole range. In other words, the control rods are adjusted so that when the spark-control lever is

fully retarded or advanced, the magneto spark-control mechanism is also fully retarded or advanced. Next, the piston of cylinder 1 is placed on its compression dead center, the spark-control lever is slightly advanced, and the magneto armature is revolved slowly in the direction in which it runs until the magneto distributor brush or sector has almost reached the contact for magneto terminal 1. In some magnetos, this requires removal of the distributor head; in others, a window cut through the distributor head exposes to view figures on the distributor rotor showing with what terminal the distributor brush or sector makes contact. The armature is now turned very slowly and the two contact points of the circuit-breaker are watched closely, the armature being stopped the instant the contact points begin to separate. When a window is cut through the distributor head, the figures on the rotor are usually so placed that it is necessary only to turn the armature-coupling part until it meshes with the coupling part, the several parts of the coupling being already fastened to the armature shaft and its driving shaft.

COOLING SYSTEM

33. While the motor is running, note whether the cooling water is circulating properly. The motor should be able to run indefinitely with the throttle just open and the spark about one-half advanced, without the radiator heating up excessively, provided that the latter has a fan to assist its cooling. If, on taking the car out on the road, it is found that the radiator is persistently overheated, the cause of such overheating should be investigated. The trouble may be found to be due to a clogged pipe, dirt or oil on the inside or the outside of the radiator, a defective pump, clogged radiator tubes, etc. Before starting, one should always see that there is plenty of water in the radiator, as an insufficient supply will cause overheating. This is particularly true in the case of the thermo-siphon system, as in this system the circulation will cease as soon as the water in the upper radiator tank falls below the bottom of the opening that leads to the engine cylinder jacket.

34. In cold weather, special attention must be given to the cooling system to prevent the formation of ice, and at all times the radiator should be watched for small leaks, for they have the effect of reducing the water supply to a point at which it will boil and therefore render inadequate service as a cooling agent.

CARE OF THE ENGINE

GENERAL INSTRUCTIONS

35. The ordinary care of a good automobile engine, when everything is working well, is a very simple matter, and comprises hardly anything more than due attention to spark plugs, lubrication, occasional testing of the batteries, with recharging or replacement as required, and seeing that the radiator or water tank is kept full.

36. Oil Supply.—All the oil supplied to the engine and oil cups should be strained; though, as the oil pump itself is probably fitted with a strainer, no additional attention at this point is likely to be required beyond occasionally taking out and cleaning this strainer. If any dirt, bits of wood, or fibers of waste get past the strainer, they are liable to make trouble if the oil is fed through any kind of check-valve or needle valve. Waste is particularly troublesome in this respect, as it shreds and a few fibers of it may very easily get into the oil without being noticed.

37. If the oil is not fed to the pistons in sufficient quantity, the engine will make the fact known by a laboring sound and a falling off in power, when both the ignition and the carbureter are in perfect order. If this occurs, a little extra oil may be put into the crank-case, where it will be thrown up into the cylinders in sufficient quantity to ease the engine until the oiler can be readjusted. A new engine should have a little more oil on both pistons and bearings than one that has run several hundred miles, and it is well to feed oil to the former until a little white smoke shows in the exhaust. Black smoke indicates too much gasoline in the mixture.

38. It is best to use the heaviest oil that the weather conditions will permit. Often it will be found that a heavy oil can be used in summer and a medium or light oil substituted in winter without a change of lubricator adjustment, owing to the light oil flowing more freely. Generally, however, an increase in feed is necessary when the lighter oil is substituted.

39. Spark Plugs.—Occasionally, the spark plugs will foul and require cleaning or replacement. How often this will occur is altogether a question of the particular carbureter used, lubricating arrangements, condition of the piston rings, and type of plug; and the only general directions that can be given are that the operator should adjust the oil and the carbureter to produce as little free carbon as possible in the cylinder, and then should learn by trial how often the plugs require inspection.

40. Knocking.—One item in the daily care of a motor that cannot well be neglected is the listening for knocks or unusual sounds. These may occur from a great variety of causes. Nearly all the causes that produce knocking grow rapidly worse if not attended to, and therefore no symptom of this sort should be neglected.

41. Carbon Deposits.—It is well to squirt about a tablespoonful of kerosene into each cylinder at the end of a long day's run, say from 75 to 150 miles or when the cylinders are still hot. This will loosen any carbon deposit that may have formed about the piston rings. Kerosene is a very efficient solvent of the tarry products that act as a binder for this carbon deposit, although, of course, the carbon itself is not dissolved. Most engines have priming cocks on the cylinder heads that may be used for introducing the kerosene; but if these are absent the kerosene may be injected through the inlet valves. If the carbon deposit is allowed to cool overnight and then is subjected to the heat of the engine the next time the car is run, the carbon becomes very hard and another layer of carbon will form over it, until a carbon knock together with a falling off in power becomes apparent. The carbon must then be scraped or burnt out or it may be removed by repeated

applications of a good carbon remover. Although there are some very good solutions of this nature on the market, too much care cannot be exercised in choosing the one to be used in order to obtain a solution that will have no harmful effect on the metal of the combustion chamber.

42. Cold Weather.—If the car is to be run during cold weather, special attention must be given to the lubricating and cooling systems.

If the car is allowed to stand any length of time, as overnight, the cold may cause the oil to become too thick to flow freely and the bearings may then become overheated, when the engine is first started, before the oil has warmed up enough to flow freely. To prevent this, care should be taken that the oil used is of sufficiently low temperature test to be used under the conditions which it will meet.

If the temperature falls below the freezing point of the water or of the mixture in the radiator, the result may be a broken pump, a cracked water-jacket, or a bursted radiator. These troubles may be avoided by drawing off the cooling water from the lowest part of the system each night or whenever the car is to be out of service for any length of time, or by using a cooling mixture that has a lower freezing point than the temperature of the weather to be met.

ELECTRIC EQUIPMENT

LIGHTING AND STARTING

43. All modern cars are equipped with electric lights, and they are all provided with some method of starting the motor besides the old method of cranking by hand.

Electric lighting was first accomplished by the use of storage batteries which were charged at some charging station. Because of the comparatively short life of these batteries, together with the inconvenience and expense of recharging, generators were finally installed in connection with the engine. These generators generally supply the necessary current for

ignition as well as for lighting, and any excess current is used in charging the storage battery. By this method, sufficient current is always to be had whether the car is running or has been standing still for some time.

44. Self-Starters.—Although several types of self-starters have been successful, the electric starter is the one universally used today. This is due to several conditions, the most important being the convenience, since the generator and storage battery are able to supply a current in excess of that required for lighting and ignition. Compressed air has been used successfully but is inconvenient because of the extra parts that are necessary and the fact that it will not operate under certain conditions.

45. Arrangement of Electric Equipment.—In order to show the relation of the different parts of the electric equipment of an automobile, Fig. 2 is presented. This illustration shows, partly in diagrammatic form, all the essential parts of a three-unit system, ignition in this case being effected by current from a dynamo-and-storage-battery circuit, a timer-distributor, and an induction coil. Fig. 2 does not represent any particular make of electric equipment, but has been prepared to show the important features and relationship of the component parts of such equipment.

The engine is cranked by the starting motor *a*, which is connected to the crank-shaft of the engine by a silent chain and sprockets; an overrunning clutch is fitted to the motor-armature shaft inside the sprocket wheel *b* so that the armature remains at rest while the engine is running under its own power. The electric generator *c* is driven by silent chain from the engine, a driving sprocket *d* being fastened to the side of the motor-drive sprocket in this particular case. Other methods of driving the generator may of course be used.

46. The electric motor *a*, Fig. 2, the electric generator *c*, the storage battery *e*, the lighting system, including the switch *f* and the lighting circuits *g*, *h*, and *i*, and the ignition system, consisting in this case of an ignition switch *j*, an induction coil *k*, and a timer-distributor *l*, are all connected in

parallel, in order that current can be drawn from the storage battery by the starting, lighting, and ignition systems independently of one another. The electric generator *c*, being in

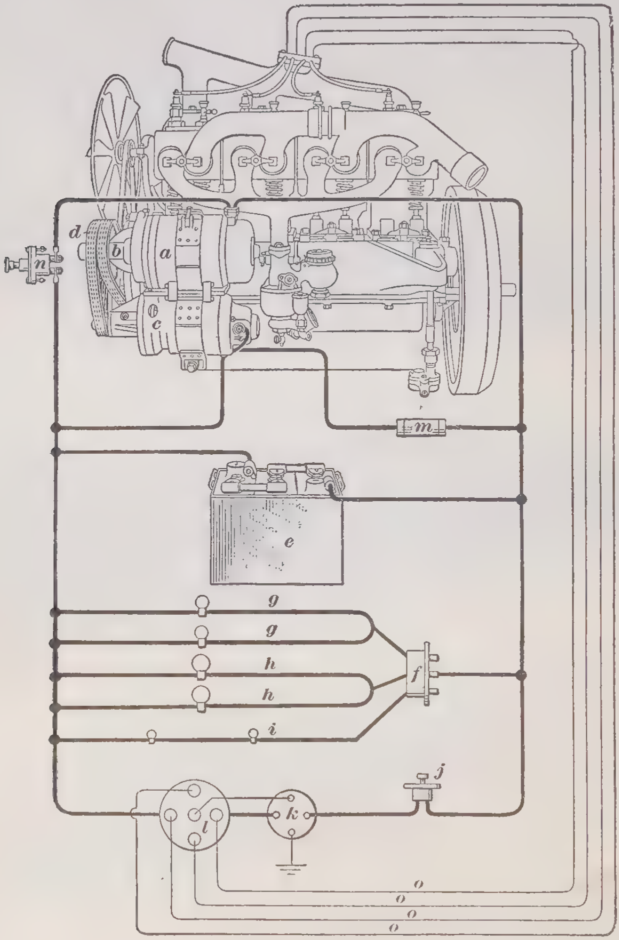


Fig. 2

parallel with the storage battery and the lighting and ignition system, can furnish current to each, independent of the other. The electric generator and the electric motor are also connected in parallel, but the generator at no time furnishes cur-

rent to the motor, because while the motor is running the generator armature is running so slowly that no appreciable current is generated.

47. A reverse-current switch *m*, Fig. 2, automatic in action, is placed between the generator and the storage battery in such a position that while it prevents the flow of electricity from the storage battery to the generator at all times, it does not prevent electricity from flowing to the electric motor when the motor-starting switch *n* is closed, or to the lights when any of the buttons of the switch *f* are pressed in, or to the ignition system when the switch *j* is closed. A storage battery connected as here shown, that is, in parallel with its source of current supply and with the electric system or systems to which it delivers current, is said to be *floated on the line.*

The wires *o* convey the high-tension ignition current from the distributor to the spark plugs; the high-tension current then returns through the spark plug shells and engine and frame of the car, that is, through a ground, to the induction coil, one end of its high-tension winding being grounded for this purpose. With proper handling, an electric system based on this principle requires very little care.

AUTOMATIC GEAR-SHIFT

48. The automatic shifting of gears has been tried and for a time seemed to have a very bright future. The advantages of this shift are anticipation of gear-shift, lack of noise, and saving of muscular effort. The great disadvantage is the necessity of a special design of the driving mechanism. Since the modern gasoline engine has not been developed along lines that would permit the adoption of this design the automatic gear-shift has been abandoned.

MANIPULATION OF THE ENGINE

STARTING AND STOPPING OF THE ENGINE

49. Preparing the Engine for Starting.—In the following discussion it is assumed that the car has been properly prepared for starting, which means that the cooling system, if the engine is water-cooled, has been filled with water, that a sufficient supply of gasoline is in the tank, that the cock in the supply pipe to the carbureter has been opened, that air pressure has been pumped up in the gasoline tank, if pressure feed to the carbureter is used, and that the engine lubrication system has been properly supplied with oil. It is also assumed, in case of electric starters, that the storage battery is sufficiently charged.

50. Before making any attempt to start the engine, the operator should be sure that the engine is disconnected from the car. This in case of sliding-gear transmissions using a quadrant means that the shifting lever is in its neutral position in the quadrant. There is no chance for uncertainty as to whether or not the gears are in neutral with the quadrant construction, but most modern cars are equipped with a ball-and-socket arrangement for shifting gears, and until one is familiar with the different positions of the lever when the gears are in mesh, the neutral position must be found by feeling.

In case a planetary transmission is fitted to the engine, the high-speed clutch, the low-speed brake band, and reverse, must all be disengaged in order to disconnect the engine from the car; in the model T Ford car, pulling the emergency brake lever to the rear also disengages the high-speed clutch. After the engine has been disconnected from the car, it is well to apply the emergency brakes by means of the hand-brake lever or the brake pedal, which is always provided with a pawl that engages with ratchet teeth on the brake quadrant for the purpose of locking the emergency brakes in position. This application of the emergency brakes is a precautionary measure, the

purpose of which is to prevent the car from rolling away from where it is standing as the engine begins to fire, provided the car happens to stand on an incline; the vibration incidental to starting the engine may then start the car to rolling down the incline, where otherwise it would stay in place. Another reason for applying the brakes in starting the engine is that so much resistance is then offered to cranking the engine, if this, through oversight, has not been disconnected from the car, as to call attention at once to this fact.

The next step after having disconnected the engine from the car is to switch on the ignition, set the spark advance lever in its retarded position, and move the throttle lever so as to have the throttle from one-quarter to one-half open. If the engine is fitted with a device for relieving the compression, which is quite rare in modern practice, this device is set in its operating position.

51. Cranking the Engine.—Before the engine can take up its cycle of operations, the cylinders must be filled with a combustible charge taken from the carbureter. This is accomplished by turning the crank-shaft either by hand or by means of the self-starter. This operation of turning the crank-shaft in starting is spoken of as *cranking the engine*. In all modern automobiles the engine is of the vertical inverted type or the **V** type, and is located under the hood; all such engines turn in a clockwise direction when viewed from the front end of the car, and, hence, counter-clockwise when viewed from the driver's seat.

52. Should it become necessary to crank an engine by hand, it must be remembered that the starting crank is normally not in engagement with the crank-shaft, but must be pushed toward the rear of the car and rotated clockwise at the same time until ratchet teeth on the crank engage corresponding teeth on the crank-shaft. During cranking, a pressure toward the rear of the car must be exerted upon the starting-crank handle; if this is not done, the starting crank disengages at once from the crank-shaft, being pushed forwards by a spring that normally holds it out of engagement.

In hand cranking, care must always be taken to pull upwards on the crank when the greatest resistance to turning is felt, that is, when a piston is on its compression stroke. If the compression is felt when the crank is past the top center, it should immediately be disengaged, rotated counter-clockwise a quarter turn, and then reengaged. The reason for this precaution is that in case of an accidental back-kick of the engine the operator will receive serious bodily injury if this back-kick occurs while he is pushing down on the starting crank. By a back-kick is meant a backward rotation of the engine, due to the mixture being ignited before the compression stroke has been completed, which, in turn, is due to failure to retard the spark sufficiently to make starting safe.

Cranking should always be done with the left hand, and the person who is doing the cranking should stand with the left side slightly turned toward the car. Then, should backfiring occur, the left arm will be thrown out of the path of the swiftly revolving starting crank. On the contrary, if the right hand is used in cranking, the right arm will be thrown directly into the path of the crank.

53. The speed at which the engine must be cranked depends on the ignition system. If ignition is from dry cells or from a storage battery, in which case the spark intensity is independent of the engine speed, the cranking can be done slowly. If ignition is from a magneto, especially if the magneto is of the type that gives a weaker spark when the spark is retarded than when it is advanced, the engine must be cranked quite rapidly; in fact, it may be necessary to spin the engine several revolutions to get up sufficient magneto-armature speed to produce a spark strong enough for ignition. By *spinning the engine* is meant holding the starting crank engaged and turning the crank-shaft rapidly by a continuous motion. Obviously, when spinning an engine, great care must be exercised to have the spark sufficiently retarded to prevent all possibility of a back-kick.

In cranking an engine by hand, the starting crank is pulled upwards with a sharp pull through about one-quarter of a

revolution; it is then disengaged, returned to its former position, reengaged, and pulled upwards once more. If the engine has been stopped with a rich combustible mixture in all the cylinders and the engine is still warm, it will usually start upon the first quarter turn of the starting crank, provided ignition is from dry cells or a storage battery. If the engine is cold, it usually requires several crankings.

54. As soon as the engine begins to fire, the throttle should be closed somewhat and the spark advanced. At first, especially when the engine and the carbureter are cold, the engine will not run regularly; but as it becomes warm it will settle down to steady running, and as soon as this occurs the throttle can be closed farther. The engine will not develop its maximum power until the cylinders and the carbureter are warmed up properly. The length of time required for these to warm up depends on the temperature and the size of the engine. Thus, in summer weather, at a temperature of about 90° F., a small engine will warm up, starting with it cold, in a few seconds; in winter, with the temperature around the freezing point, the same engine may have to be run a couple of minutes, and a large engine much longer, before it is warm enough for satisfactory operation. If the car must be run as soon as the engine fires but is still cold, a much greater throttle opening is required than after the engine is warmed up. Running the car in low gear a short distance will help heat the engine.

If, in cold weather, the throttle is closed too soon after the engine has begun to fire, the engine is liable to stall, which means that it will suddenly slow down and stop, even though the throttle is opened more as soon as the slowing down is noticed. Stalling does not signify that the ignition system is out of order; it is due to the fact that the carbureter is not able to supply a sufficiently rich mixture at a low engine speed while the fuel is still cold. If the carbureter is fitted with a dash control or a steering-post control for enriching the mixture, enriching should be done when starting a cold engine, making the mixture leaner again as soon as the engine and the carbureter warm up.

Stalling of the engine immediately after starting is most pronounced with engines having the carbureter located very low and not fitted with a hot-water jacket or a hot-air intake. Little trouble was experienced with the stalling of such engines when high-grade gasoline was available; however, the low-grade gasoline now on the market does not vaporize properly in cold weather unless the carbureter is fitted with at least a hot-air intake.

55. No specific directions applicable to all cases can be given as to how to crank the engine when a self-starter is fitted. The self-starter which has been most generally adopted is in reality a mechanical means of cranking the engine. A motor is geared to the crank-shaft of the engine and draws its electricity from a storage battery. The storage battery is kept charged by a generator driven by the engine. The closing of a switch—done with the foot—is all that is necessary to start the engine, the hands being free to regulate the throttle and spark levers. The firing of the engine must be arranged for just the same as in hand cranking; that is, the throttle lever and the spark advance lever must be properly placed, provision must be made for getting a rich mixture into the cylinders, and the ignition must be switched on.

The details of how to operate any self-starter are usually given in an instruction book delivered to the purchaser upon delivery of the car; if this instruction book is not available, another copy, as a general rule, is readily obtained, free of charge, from the maker of the car or from the nearest selling agency. In many cases the desired information is easily secured from owners or drivers of the same make and model of car, or from garages. In case all these sources of information fail, the hand-starting crank can be slipped in place and used until the operator of the car has studied out for himself how the self-starter can be made to perform its function.

56. Most modern cars are equipped with the single ignition system using a generator and a storage battery to supply the necessary current, in this way eliminating the magneto, dry-cell battery, etc. In this single ignition system a generator

driven by the engine is used to charge a storage battery and this storage battery supplies current, not only to the ignition when starting, but also to the starting motor and lighting system.

When the engine is started, the ignition system draws its current from the storage battery but as the engine picks up speed the generator builds up a current of greater strength than that of the battery. In order to save the battery as much as possible, the ignition current is taken directly from the generator as soon as the generator current becomes greater than the battery current, an automatic switch being used for this purpose. This automatic switch is so arranged that the ignition system will draw its current from the strongest source, since both the battery and generator currents will vary in strength.

In the few cars using a magneto for ignition, the ignition system is independent of both the starting and lighting systems. A high-tension magneto is used to furnish ignition current for both starting and running without the assistance of a battery of any kind.

57. An engine may be started on a down grade without the aid of either a starter or crank by allowing the car to coast with the clutch out until the car has gained considerable headway. The clutch should then be let in gently, the gears having been set in high and the spark and throttle levers in their starting positions.

58. To stop the engine, the throttle should first be partly closed, so that the engine will run slowly, and the ignition switch should then be opened. This will kill the engine but will retain an unburned charge in one or more of the cylinders to assist in starting. If the stop is permanent the switch key should be removed to avoid accidental starting, and to make sure that the ignition current is cut off. In most systems, the storage battery will be run down if the ignition switch is left closed. When possible the gasoline should be shut off close to the tank to avoid waste by leakage. A small amount of kerosene squirted into each cylinder after a long run will help to prevent the collection of carbon deposits.

ADJUSTMENTS AND REPLACEMENTS

TIMING THE VALVES

59. When a column of gas moves rapidly, as in its passage through the admission or exhaust valves of an engine, considerable force is required to bring it to rest suddenly. When the force resisting the flow is small, it requires a considerable interval of time to bring the gas to rest. This is very noticeable in engines having automatic valves, in which the force tending to close the valves is small. For this reason, the valve timing of a high-speed automobile engine must be radically different from that appropriate to stationary engines. As the beginning and end of the piston strokes represent considerable crank-angles with very small piston movement, advantage is taken of this fact to hold the valves open for a considerably longer time than would theoretically be required in order to give the maximum opportunity for the movement of the gases.

The exhaust valve should open at a crank-angle between 30° and 40° before the end of the expansion stroke. This represents from one-twelfth to one-ninth of a revolution, and approximately from 5 to 10 per cent. of the piston stroke. It is a common practice, with automobile makers, to mark the flywheel rim with reference to some convenient fixed object, generally the vertical center plane of the motor. These marks may indicate the inner and outer dead centers, or they may indicate what the maker has decided is the suitable crank position for the exhaust valves to begin to open. In the latter case, it is generally best to adhere as nearly as possible to the point of opening thus indicated.

Although in the majority of automobile engines, the exhaust valves close at the end, or dead center, of the exhaust stroke, it has been demonstrated conclusively that there is a marked advantage in holding the valves open until the crank is 5° or even 10° past the center. The latter angle represents a piston movement of only about 1 per cent. of the stroke, and no fresh

mixture will enter during this period, whereas the prolonged opening of the exhaust valve permits the gases in the exhaust pipe to create a slight suction in the combustion chamber by virtue of their own inertia, thus tending to induce the flow of a larger charge of fresh mixture. If the exhaust valves are held open until the crank is about 10° past the dead center, it is unnecessary to open them quite so early on the expansion stroke as would otherwise be considered necessary. A good average rule is to open the exhaust valves 35°, or practically one-tenth of the circumference of the flywheel, before the end, or dead center, of the expansion stroke, thus making the total opening of the exhaust valve about 225° of the revolution of the flywheel. If the engine is to run at speeds upwards of 1,500 revolutions per minute, an earlier opening and later closing may be of advantage.

60. If the inlet valve is located over or beside the exhaust valve, it should open with the crank about 5° past the center. If it is on the opposite side of the engine from the exhaust valve, it may open on the dead center, thus permitting a direct suction across the combustion chamber that will greatly increase the power of the engine. The inlet valve should close about 20° to 30° past the dead center at the end of the suction stroke, or approximately $2\frac{1}{2}$ to 5 per cent. of the piston stroke. The reason for holding open the inlet valve is that at high speeds the inertia of the incoming column of the mixture will carry it into the cylinder after the return stroke has begun.

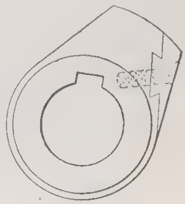


FIG. 3

61. The valve timing is usually adjusted by threaded adjusting ends on the push rods; also, by shifting the two-to-one gear one tooth or more in relation to the pinion. If the total duration of opening of the exhaust valve is less than 230°, after making due allowance for necessary clearance between the push rod and the valve stem, it is advisable to substitute new cams or else to build out the old ones. This can sometimes be done by dovetailing in a segment, as shown in Fig. 3. Generally, it will be necessary to anneal the cams

before this can be done. The inserted piece is better located if possible in the closing face of the cam, as it is subjected to less wear on that face that on the other. It should be made of tool steel, and, after being tightly driven in and fastened with a rivet or screw, should be hardened with the cam.

If the inlet valves are operated by the same shaft as the exhaust valves, it may be impracticable to alter the valve timing by shifting the two-to-one gears. In this case, it will be necessary to alter the cams.

TIMER ADJUSTMENT

62. The timing of the ignition may be tested for uniformity by marking the flywheel in the same manner as for timing the valves. In case it is found that the cylinders are unequally timed, the timer should be adjusted according to its construction. If the timer has a cam that presses springs in contact with contact screws, the timing may be modified by adjusting the contact screws so that a little more or less movement of the cam is required to produce contact. If, as in Fig. 4, the timer has a fiber barrel *a* with an inlaid copper or brass segment *b*, the only way the timing can become incorrect is through wear of the hardened-steel blocks *c* at the ends of the contact brushes, or through loosening and slipping of these brushes, which are generally slightly adjustable on their insulated bases *d*.

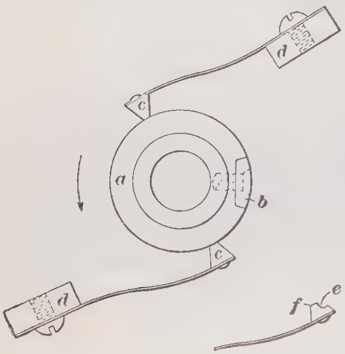


Fig. 4

When these blocks have worn down considerably, it is well to grind away a portion of their contact surface at the bearing edge, as seen in the detail at *e*, otherwise considerable pressure will be required to make good contact at the leading edge *f*, and this will wear away the barrel and metal segment unnecessarily fast. When the timing is tested, the spark should always

be retarded to its fullest extent, and in this position the spark should occur in each cylinder exactly on, or a definite number of degrees after the crank has passed, the dead center.

REPLACING VALVE KEYS

63. On account of the inertia of an exhaust valve of an engine running at high speed, the springs that close the valve must be very stiff, and it is sometimes a problem to get them back in place after they have once come out—as may accidentally happen when grinding the valves.

To replace the spring, it must first be compressed in a vise and bound securely on opposite sides by two pieces of annealed wire. When this is done, the spring may be put back in place, the valve dropped in, and the washer and key properly inserted. Then the wires binding the spring may be cut with a pair of pliers and the spring allowed to expand. The spring should bear squarely on the washer.

In a few engines, no washer or key is used, but the lower end of the spring itself is bent inwards and flattened to go in a slot in the valve stem. In this case, the spring may be taken out from the valve stem by first blocking up the spring in the same manner as is done when the washer is used, and the spring may be replaced by compressing and binding it as just described, the valve being held in the proper angular position with a screwdriver, while the end of the spring is first pulled and then pushed into position with a strong pair of pliers.

64. Valve-stem keys should be made of annealed tool steel, and should not be made too close a fit in the valve-stem slot, because they are likely to bend slightly in use. Ordinarily it is cheaper to buy these keys of the maker of the car than to make them specially. One or two spare keys should always be carried.

VALVE GRINDING

65. On account of the blow struck when the valve is forced against its seat and because of the action of the hot gases, it becomes necessary at times to grind the valves to a bearing on

the valve seats. This is especially true of exhaust valves as they are more exposed to the influence of the hot gases than the inlet valves, which are somewhat cooled by the cool incoming gases. When *seating* valves, the grinding should be continued until both valves and seat show a complete circle, at least $\frac{3}{32}$ of an inch wide, of dull finish where the two parts have been in contact and have been cut by the grinding material. For perfect "seating" this dull finish should cover the entire surfaces that are in contact. Dark places indicate wear and should be completely ground out, while pits, which also indicate erosion, are sometimes so deep that in order to remove them completely it would be necessary to grind away too much of the valve, therefore if a very small pit is surrounded by a perfect bearing it may be neglected. Trouble of this sort is avoided if the valves and seats are made of an alloy steel especially made to withstand pitting. When valves or their seats are found in a very bad condition it is a good practice to use a valve seater to true up the seats, and have the valves trued up in a machine shop or new ones substituted.

TAKING OFF AND REPLACING CYLINDERS

66. When the engine is assembled at the factory all parts are generally marked to identify them, and these marks should be located in case it becomes necessary to take down the engine at any time. If these marks cannot be found, some method should be taken to put permanent marks on all parts before they are removed so that they may be replaced in their original positions. Now that mono-block cylinders are so extensively used, a great deal of this trouble has been done away with, but the cylinder and cylinder-head castings (when separate) should be carefully examined in order that there may be no doubt as to the manner in which they go together.

When the cylinders are off, care should be used to avoid handling the pistons in such a manner as might break their lower edges, which are very thin. When the cylinder is off, it is a good plan to inspect carefully the surface of the cylinder wall and the piston and ring surfaces, to see if they have been

scored by lack of oil or water. The cylinders and pistons of a well-kept engine will show a bright, almost mirror-like surface, free from scratches.

67. If the piston rings are clogged with carbon, it is, on the whole, better to clean them as thoroughly as possible with kerosene, while in position, rather than to take them off, as the bending of the rings is liable to strain them out of true, and cause leakage when they are replaced. In case it seems advisable to take off the rings, each ring should be marked with a small, sharp prick-punch, and the corresponding groove marked, so that each ring will be restored to its own groove. To take off the rings properly and without risk of straining requires considerable care. A good method is to use three or four narrow strips of tin or thin brass, which are first slipped under the ends of the ring nearest the head, and gradually worked around until the ring is out of its groove. The same strips are used to bridge the grooves when the other rings are taken out.

When a cylinder is to be replaced, the piston rings must be compressed and tied, or otherwise confined, or it will be a difficult matter to get the piston into the cylinder. As each ring is started in the cylinder, its binding is removed.

REMOVING CARBON FROM THE COMBUSTION CHAMBER

68. A refractory deposit of carbon in the combustion chamber may be loosened with kerosene and scraped out with anything convenient, such as a cold chisel or an old file with the end ground sharp. If it is inconvenient to take off the cylinder, it is frequently possible to remove or reach the carbon through the spark-plug or valve holes, by the use of scrapers like those shown in Fig. 5, which are generally made for the purpose from iron rods with the ends flattened and bent to suit the conditions to be met. An exceedingly useful outfit is a battery lamp of 2 or 3 candlepower, with a length of No. 16 lamp cord, by which it may be connected to the battery, and an ordinary plain (not magnifying) dentist's mirror. The lamp is

screwed into a miniature socket, and a length of iron wire is wound into a coil around the cord adjacent to the socket, the coil being extended to include the socket and the lamp, thereby forming a protective cage for the latter. It must, however, not touch the lamp.

69. By the use of such a lamp, almost every inch of the combustion chamber of an ordinary engine can be explored and scraped, and the carbon can be pulled out through the spark-plug hole; or, if more convenient, the exhaust valve may be opened and the accumulation allowed to fall into the exhaust port, from which it will be carried to the muffler. It is better, however, to take the exhaust valve right out than simply to open it by the cam, as only in this way can one be sure that

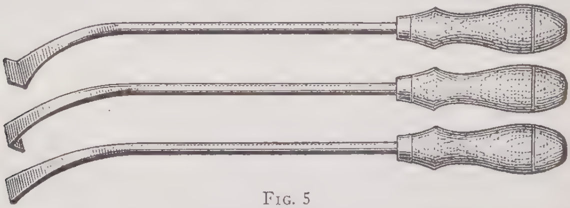


Fig. 5

none of the carbon lodges between the valve and its seat, thus necessitating regrinding. When the carbon is scraped out in this manner, it is better not to use kerosene unless it is necessary, as it increases the likelihood of loose carbon fragments sticking to the combustion-chamber walls and causing further trouble from preignition. It should be understood that the piston head is considered as part of the combustion chamber wall.

When carelessly done, scraping is liable either to scratch the walls of the chamber or to leave small points of carbon sticking out into the chamber from the walls. Any roughness in the chamber is conducive to the rapid collection of carbon and the carbon points may become incandescent and cause either preignition or back-firing.

70. The more convenient and easier method is to burn the carbon out with the aid of an oxygen torch. When using the oxygen torch, the oxygen is burned under pressure in the

combustion chamber, the oxygen combining with the carbon and the pressure blowing out all loose particles.

71. The carbon may also be removed by taking out the spark plugs and rotating the engine until two of the pistons are on their upper dead centers and then filling these combustion chambers with a good anti-carbon solution. The other cylinders must be then treated in the same manner. This solution should be left in the chamber for several hours, at the end of which time the solution should be drawn off. The carbon may then easily be removed with the aid of scrapers or the spark plugs replaced and the engine run. If the chamber is not scraped it may be necessary to repeat the operation several times before the carbon is entirely removed.

MISCELLANEOUS SUGGESTIONS

COLD-WEATHER HINTS

72. Cooling Water.—In cold weather, the circulating water, the oil, and the carbureter require special attention. If the car is to be run regularly during the winter, it is advisable to use a non-freezing mixture in the water-jacket. If the car is not to be used regularly, and is kept in a warm place, it may not be necessary to employ such a mixture, but in that case great care is necessary to prevent the water from freezing unexpectedly. If the car is kept in a cold barn, the water should be drawn off completely after the car has been used, and the back of the car jacked up while the drain cock is open, so that there will be no water pockets in which the water may freeze and obstruct the circulation. If the water freezes in the pump, the latter is likely to be broken when the car is started the next morning. If water freezes in the water-jackets, it will burst the jackets unless they are made of copper. When the car is left standing for an hour or so, cloths or lap robes may be thrown over the radiator to check the cooling; this is cheaper and safer than to leave the motor running.

73. Antifreezing Solutions.—Glycerine, alcohol, and calcium chloride are the substances most used to prevent the freezing of the water in the cooling system. A 30-per-cent. solution of glycerine in water freezes at 21° F.; and a solution of one part of glycerine to two parts of water is safe from freezing at 10° or 15° F.; 40-per-cent. solution freezes at zero. A small amount of slaked lime should be added to neutralize any acidity in the solution. Glycerine has the objection that it destroys rubber, and the solution fouls rather quickly.

A cheaper mixture, and one preferable where the temperatures encountered are likely to be below 15° or 20° F., is a solution of calcium chloride. Only chemically pure calcium chloride should be used; the impurities in ordinary commercial calcium chloride sold as chloride of lime are apt to attack some of the metals of the cooling system, especially aluminum, zinc, and solder. Pure calcium chloride is very cheap when bought in bulk, and does not materially affect metals except zinc. A saturated solution is first made by adding about 15 pounds of the chloride to 1 gallon of water, making a total of about 2 gallons. Some undissolved crystals should remain at the bottom as evidence that the solution is saturated. To this solution is added from 2 to 3 gallons of water, the former making what is called a 50-per-cent. solution. A little lime is added to neutralize acidity. A 50-per-cent. solution freezes at −15° F.

74. Whether glycerine or calcium chloride is used, loss by evaporation should be made up by adding pure water, and loss through leakage by adding fresh solution. In using the chloride, it is important to prevent the solution from approaching the point of saturation, as the chloride will then crystallize and clog the radiator, besides boiling, and failing to cool the motor. A 50-per-cent. solution has a specific gravity of 1.21, and should be tested occasionally by means of a storage-battery hydrometer. It is equally important to prevent the water from approaching the boiling point, whatever the density, as boiling liberates free hydrochloric acid, which at once attacks the metal of the radiator and cylinders.

A solution of two parts of glycerine, one part of water, and one part of wood alcohol has been recommended, which is said to withstand about zero temperature.

75. Certain mineral oils used for the lubrication of refrigerating machinery are recommended for cooling, because they remain liquid at very low temperatures. They are not particularly good heat conductors, however, and will not keep the motor as cool as does the water solution. If the oil is used, it must be cleaned from the radiator by the use of kerosene and oil soap before water can again be used effectively.

76. Lubrication.—As regards lubrication, the principal danger is that the oil will thicken from the cold so that it will refuse to feed. This is avoided by using oil that, as determined by the cold test, remains liquid at lower temperatures than ordinary oil or by using a grade of oil recommended by the manufacturer for that particular engine under such conditions. Charts are issued by many oil companies setting forth the quality of oil to use under various conditions, and it is a good practice to follow their recommendations in this respect. These charts can always be obtained free of charge upon request.

77. Carbureters.—The quality of the gasoline now obtainable is such that considerable heat is required for its complete vaporization. For this reason, in modern practice it is customary to heat the interior of the intake manifold, in addition to supplying hot air to the air intake of the carbureter. In some cases the heating is accomplished by combining the intake and exhaust manifolds into one piece; in others, by having a projection extend from the exhaust manifold into the intake manifold, directly over the mixing chamber, and by other similar devices. To assist in starting during cold weather, the carbureter may be warmed by the application of hot wet cloths to the outside of the mixing chamber.

GASOLINE-HANDLING PRECAUTIONS

78. The user of gasoline should never forget that it is not the liquid gasoline, nor yet the vapor of gasoline, that is explosive, but only the mixture of gasoline vapor and air in the right proportions. If the liquid gasoline were not so volatile, it would be as safe to handle as kerosene, in which one may plunge a lighted match without igniting it, the match instead being extinguished by the cold oil. But since gasoline evaporates rapidly when exposed to the air, it is not enough to avoid bringing a lighted match, a flame, or an electric spark within the vicinity of the liquid—as, for example, when gasoline has been spilled on the floor or on the ground—but one must also avoid any possible source of ignition anywhere in the neighborhood until the air has changed sufficiently to dilute the vapor below the point of inflammability. Almost all the accidents due to the handling of gasoline arise simply from carelessness in neglecting these precautions.

79. Air saturated with the vapor of gasoline will burn if allowed to come in contact with fresh air and is ignited, but it will not explode, as the proportion of gasoline vapor in it is too great. It follows that a can or tank containing gasoline is safe from explosion if the vapor of the liquid is saturated, and this is the condition that will naturally obtain if the liquid has been drawn off so gradually that its place has been filled with air and saturated vapor. If, on the other hand, the can or tank has been emptied quickly, air will enter it to take the place of the liquid poured out, and the proportion of vapor will not be sufficient to prevent it from being explosive. This is the most dangerous condition possible, and calls for the strictest precautions to prevent the ignition of the mixture therein.

80. All these points relating to the faulty action of engine, as well as details of lubrication, valve grinding, carbon removal, etc., are taken up fully in later papers on *Troubles and Remedies*.

MANAGEMENT OF AEROPLANE ENGINES

FIXED-CYLINDER ENGINES

INTRODUCTION

1. Aeroplane engines are operated under the most severe conditions; for this reason, their construction must approach a degree of perfection far beyond that required in automobile- or marine-engine service. An aeroplane, being heavier than the air through which it operates, can continue its flight only as long as the power plant functions properly, and the accidental stopping of the engine, together with the forced landing that follows, is accompanied by considerable danger. Many serious accidents have resulted from this cause. On the other hand, the unexpected stopping of an automobile or marine engine is usually little more than an inconvenience, and very rarely results seriously to the operator.

2. The two main factors that influence the construction of all aeroplane engines are great power and extreme lightness. The average automobile engine will not, on account of its weight, prove satisfactory in aeroplane service even if it measures up to the required standard of power and reliability. A perfected automobile engine will weigh from 15 to 25 pounds per horsepower, whereas aeroplane engines have been developed to such a degree that the weight has been brought as low as 2 pounds per horsepower.

3. Aeroplane engines run at nearly full capacity all of the time. This means that they must have full compression, maximum temperature, and maximum pressure, and be exposed to maximum vibration all of the time. Lubrication and cooling under these conditions become greater problems. For instance, an automobile slows up at different times during a run, allowing the oil film to be renewed under the crank-shaft. In aeroplane engines, there is no such easing up of the speed, and greater pressure is required to maintain the required lubrication. Furthermore, aeroplane engines run at high temperature continually, because of the necessarily light weight of the cooling system. The crank-shaft is exposed to greater strain on account of the uneven condition of the air through which the propeller is working. Even the best balanced propellers vibrate or tremble to a certain extent, and all this vibration is transmitted to the engine.

4. Aeroplane engines must run at high altitudes, with consequent varying conditions of the atmosphere and temperature, and at different angles. These conditions present problems that must have considerable attention when the engine is designed. There are other important factors that influence the action of an aeroplane engine, but those mentioned will serve to show the necessity of making frequent adjustments and repairs to keep the engine in the best possible condition, and will explain why the normal life of the aeroplane engine is much shorter than that of a gasoline engine used for any other purpose.

CARE AND MAINTENANCE

STARTING

5. Preliminary Preparations.—If the engine is a new one, or if it is new to the crew in whose charge it is placed, a thorough inspection should be given before a flight is attempted. This must be done systematically and with extreme care, for if any of the details are carelessly or hurriedly over-

looked and something goes wrong with the engine in flight, the loss of life of the pilot and others who are in the plane may be the penalty.

The following important points should be given attention, but there may be others peculiar to certain engines, which the common sense of the mechanic in charge, as well as an investigation of the engine, should reveal.

6. All accessible bolts and nuts should be gone over carefully and tightened, wherever possible, and securely locked by cotter pins or locknuts. The propeller mounting should be examined. The flange bolts must be drawn up tightly and properly locked with cotter pins. The retaining nut and bolt must be tight and locked in place by the lock wire.

With some one in the pilot's seat moving the spark and throttle levers, an inspection should be made to see whether the connecting mechanism operates the throttles and timing device throughout their entire range. The throttles in the carbureter, or carbureters, must be closed when the throttle lever is in the closed position. This is exceedingly important, as the throttle control may not properly fit the engine and the throttle will remain open when it should be closed. As a result, when the mechanic cranks the engine, the machine may start ahead and the propeller strike him. On the other hand, the control must give a full throttle opening. It is equally important that the cam housing be in its fully retarded position when the spark lever is in the corresponding position. Otherwise, the spark may be advanced when the spark lever indicates full retard, and a back kick may result seriously to the mechanic when cranking the engine. The operating mechanism must be so adjusted as to allow full advance of the spark also.

7. The electrical connections should next be looked over carefully. See that all connections are properly soldered, clean, and firmly attached at the distributor, generator, storage battery, switch, voltage regulator, etc. All terminal nuts must be held by cotter pins or lock washers. Each wire must be inspected to see that it is properly insulated, and held so that

it cannot chafe against any metal parts and wear through the insulation. This is particularly important in connection with the ground or short-circuit wire, because if the insulation wears off, the bare wire will cause a short circuit when it comes in contact with the metal of the engine. The effect of this will be the same as having the switch closed all of the time, making it dangerous for the man who cranks the engine. The switch should be examined and all loose parts properly tightened. If strands of wire come loose on a cable inside the switch, one or more of these strands may touch the opposite part of the switch and short-circuit it. There must be no corrosion that will prevent the switch from making contact, as the motor will then fail to stop unless all of the gasoline supply is cut off; or, it may be the cause of injury to the man who starts the engine.

8. In examining the breaker points of the magneto, it is safer first to break the connection between the distributor and the collector brush, as in many magnetos the connection for short-circuiting the current is located in the cam cover. If this precaution is not taken, the engine is likely to start when being turned over to see how the breaker points operate. If the engine has a battery system with timer-distributors, the individual breakers must be tested to see that they break their respective circuits at the same time, as will be explained later. When the breaker has been examined and the gap between the contact points is of the proper width, the distributor head should be removed and wiped out carefully. Examine the secondary wires leading from the distributor to the spark plugs, and then remove the plugs. Clean and adjust the points, and test them to see that the spark occurs at the gaps properly, and look for cracked porcelains. It is well to remember in this connection that a spark plug that has been used and has proved satisfactory is more reliable than a new one.

9. After the ignition system has been gone over thoroughly, it is well to turn attention next to the valve-operating mechanism. All valves should operate freely and have the correct clearance. This clearance is given in the instructions sent

out by the manufacturers of all engines and the adjusting of the clearance should not be done without having this information at hand. When this is known, turn the propeller until both valves are riding on the round part of the cams, in which position they are entirely closed. A gauge, or feeler, should be used to obtain the correct clearance. The tension of the closing springs should be tested, as it is important that they be of the proper strength.

10. The compression of the engine should be tested. This is done easiest by pulling down on the propeller, making sure that the switch is in its open, or "off," position. If the compression is good the propeller will offer considerable resistance to turning, and will rebound several times if released when the piston of one of the cylinders is at the top of a compression stroke. If little resistance to turning of the propeller is experienced with some cylinders, the location of these can be determined by removing the spark plugs, then putting one in each cylinder at a time, and testing the compression in sequence. The causes of lack of compression are taken up in another Section. Examine all water and oil connections and make sure that they are tight and in good condition.

11. Routine of Starting.—There are certain details that form a part of the routine of the mechanics in charge of an aeroplane before a flight is undertaken. These consist of making sure that the gasoline tank is filled, that the oil reservoir contains the proper amount of oil, and that the cooling system is filled with water. If the cooling system is empty, the air vent cock should be left open until water flows out of it, to prevent the formation of air pockets. The connections between the radiator outlet and pump inlet should be examined for leaks. Leaks at this point will permit air to be drawn in, displacing water, and may cause overheating. All exposed parts, such as rocker-arms, valve stems, etc., should be oiled. If the valve or valves in the main gasoline line are open, the engine is ready to be started.

After the pilot has taken his seat, he should see that the throttle is slightly opened and the spark fully retarded before

the propeller is turned. The man at the switch and the man at the propeller, if the engine is to be started by hand, must have a perfect understanding with each other to eliminate any chance of an accident. Usually a regular system is followed in each flight from the time the pilot takes his seat until the aeroplane leaves the ground.

12. For example, after the mechanic in charge makes sure that the wheels are properly blocked and a mechanic is stationed at each wing tip, he reports to the pilot that everything is all right. He then goes to the front of the aeroplane and calls "Switch off," to which the pilot replies "Switch off," after making sure that it is in the "off" position. He then rotates the propeller through four or five revolutions to charge the cylinders, steps back, and calls "Contact," and the pilot repeats, "Contact," closing the ignition circuit as he does so. The mechanic then grasps the propeller blade, which was previously stopped in the best position for starting, with his fingers on the upper edge and the backs of his hands toward him, and gives a sharp pull downward, at the same time leaping backward clear of the blade. The hands must be withdrawn instantly, as in the case of a back kick there is danger of injury to the operator. If the engine fails to start, priming the cylinders may remedy the trouble. It is usually necessary to do this if the engine has been standing long enough to become cold. If the engine is a new one it is advisable to squirt a little lubricating oil into each cylinder and swing the propeller around several times before starting, to make sure that the cylinder walls are well lubricated until they receive oil from the oiling system of the engine. In case the engine refuses to start, the trouble should be traced out.

13. After the engine starts, the spark should be advanced and the throttle adjusted so that the engine does not race. It should be allowed to run for a few minutes to bring it up to normal working temperature before beginning a flight. The exhaust should be observed, and its condition noted. A black or flaming exhaust indicates too much gasoline, while blue smoke indicates too much oil. An experienced operator can

tell by the sound of the exhaust whether or not all of the cylinders are firing properly. He can also sense the action of the engine by its "feel" at different throttle positions. At a signal from the pilot, the blocks are pulled away from the wheels, and the aeroplane starts.

It is a dangerous procedure to attempt to start an engine immediately after it has stopped. A burning particle of carbon or an overheated spark plug may cause preignition and a disastrous back kick. The engine should be allowed to cool off for a few minutes.

14. In order to facilitate the starting of an aeroplane engine and to eliminate the danger in the turning of the propeller by hand, self-starting devices are employed in many aeroplanes. These starters were found to be essential in military machines, and they are gradually being applied to commercial aeroplanes because of their greater convenience and safety.

Starting devices are made in two general types, namely: those in which compressed air is employed; and electric starters, in which an electric motor is coupled up with the crank-shaft. Both types serve to turn the crank-shaft through several revolutions when it is desired to start the engine.

15. Compressed-Air Starters.—The compressed-air starter is made in two forms. In one form, the air under compression in a tank is allowed to flow into the cylinders in the rotative firing order of the pistons, entering each cylinder when the piston is at the top of its compression stroke. The pressure of the air forces the piston downwards successively in each cylinder until the engine picks up its cycle of operations and runs on its own power. This form has not come into very general use because of its inability to turn the engine over when the piston to which the air is first introduced is on its dead-center position.

16. Another form of compressed-air starter that has proved more popular than the one described briefly in the last paragraph, is shown in Fig. 1 (*a*), (*b*), and (*c*), all like parts being lettered the same in the three views. It is positive in

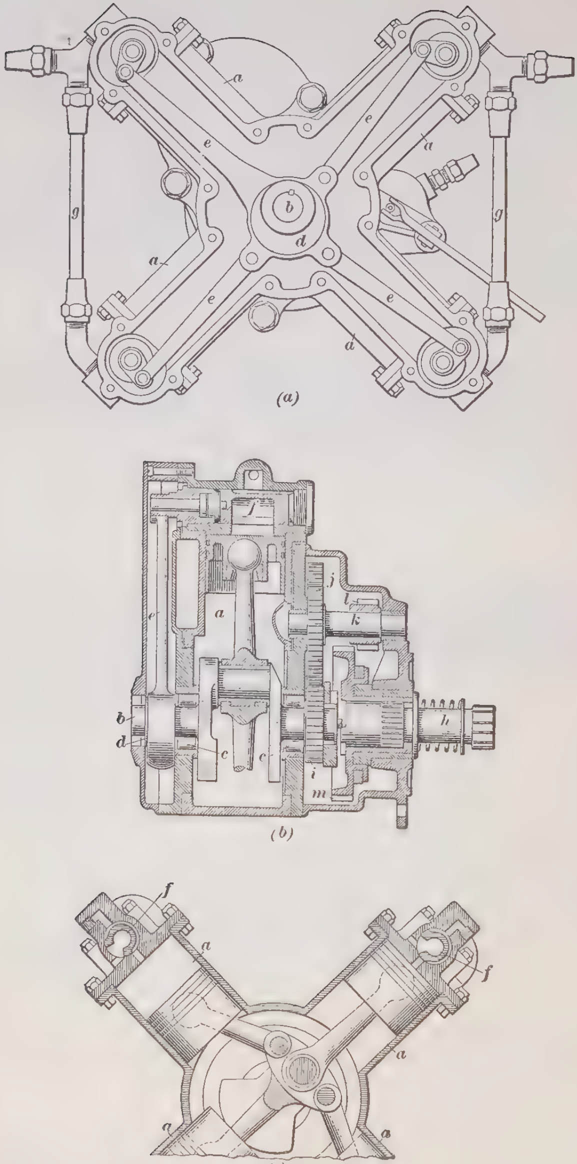


FIG. 1

its action in that it is coupled to the crank-shaft and rotates with it. It is used as a motor when starting the engine and as a compressor to charge the air reservoir when the engine is running. It has four cylinders *a* arranged radially around a crank-shaft *b*, the pistons being connected to the crankpin through connecting-rods having ball-and-socket bearings in the pistons. The crank-shaft is carried in roller bearings *c* in the frame and to one end of it is fixed an eccentric *d* to which the eccentric rods *e* are attached. These rods *e* are connected to short cranks on the ends of the stems of the four oscillating valves *f* in the heads of the cylinders. The pipes *g* supply high-pressure air when the device is used as a motor for starting and are the discharge pipes when it is used as a compressor. The shaft *h* is connected by a coupling to the crank-shaft of the engine. When the device is to be used as a starter, the speed is reduced by the gearing shown in (*b*). The pinion *i* on the crank-shaft meshes with the gear *j* on the shaft *k* that carries the pinion *l*. On the connecting shaft *h* is a gear *m* that may be thrown into action by moving the pinion *l* into mesh with it. When this is done, the starter drives the shaft *h* and so turns the engine crank-shaft at a speed of about 150 revolutions per minute, the starter shaft *b* turning at about 1,400 revolutions per minute. The adjacent faces of the pinion *i* and the gear *m* are made to form a jaw clutch, and when this clutch is engaged by moving the gear *m* forward, the engine drives the device directly at high speed, and it acts as a compressor to recharge the air reservoir. When the air pressure reaches about 230 pounds per square inch, the device is automatically thrown out of action.

17. When it is desired to start the engine, the pilot moves a lever that opens the air cock between the compressed-air tank and the engine, permitting air to enter the cylinders in order, this order being controlled by the oscillating valves. The air forces the pistons downwards, turning the driving shaft of the starter, and imparting motion to the crank-shaft of the engine. To recharge the tank, a button on the control valve is pressed, placing the compressor in operation. The engine is run at

low speed while the connection is being made, but is then speeded up to from 1,200 to 1,400 revolutions per minute to force the air into the tank.

The engine should never be run more than one and one-half minutes with the compressor engaged. Failure of the device to produce at least 125 pounds pressure in this length of time is due to leaks or to a lack of oil. If placing a pint of heavy motor oil, with a tablespoonful of motor graphite mixed with it, in the case of the starter does not remedy the trouble, examine the connections between the tank and the control valve, the plug in the tank, the tubing connecting the tank to the control

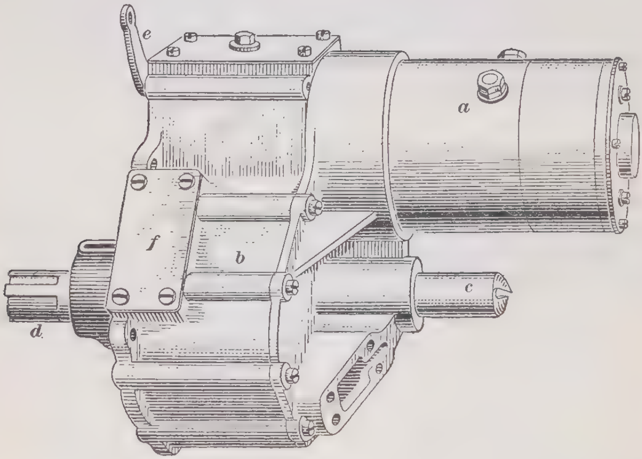


Fig. 2

valve, the control valve itself, and the fittings that connect the control valve to the pressure gauge, to see if there is any leakage at these points.

The starting motor should never be stopped with the pump engaged, as it puts a strain on the transmission gears, if the motor kicks back. When the required pressure is reached, or the engine has run one and one-half minutes with the pump engaged, the pump is released by pulling up the safety valve, and holding it up until the pump releases. No attempt should ever be made to start the engine with the pump engaged. Only one pint of oil should be placed in the starter at a time.

18. Liberty Starter.—The Liberty starter illustrated in Fig. 2 possesses the distinctive feature of combining both hand starting and electric starting in a single compact unit. The hand starter is used when the storage battery fails to operate. The starting device consists of a motor *a* that is used for electric cranking; a case *b* that carries the reduction gear, and that is both waterproof and oil-proof; a shaft *c* to which a hand crank can be attached to crank the engine; a shaft *d* that is

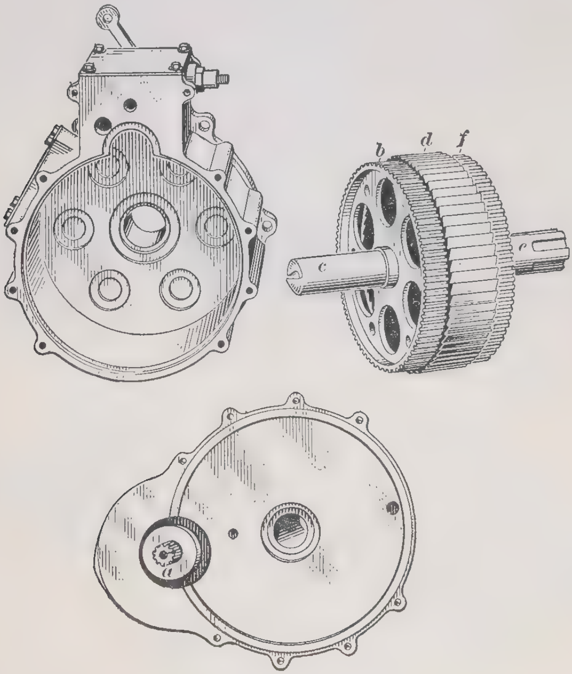


Fig. 3

coupled to the crank-shaft of the engine, and through which the engine is driven; and a switch handle *e* that connects to a cord or wire running back to the driver's control board for the purpose of operating the electric starter.

The starter unit is mounted on the cranking end of the engine, or on the end opposite the propeller, and is in direct line with the crank-shaft of the engine, thus relieving the shaft and main engine bearings of any strain. In effect, the starter

casing forms a part of the crank-case. Its rear location does away with air resistance, and makes the use of specially designed radiators unnecessary.

19. A partially disassembled view of the starter is given in Fig. 3. The small gear, or pinion, *a* is carried on the end of the starting-motor shaft and meshes with the large gear *b*. The gear *b* has twelve times as many teeth as the pinion *a*, and hence there is a gear reduction of 12 to 1 between the two gears; in other words, the pinion rotates twelve times for every revolution of the larger gear. The gear *b* is fastened to the hand cranking shaft *c*, but there is a differential construction inside of the gears connecting the shaft *c* with the engine driving shaft *e*, that gives a reduction ratio between gear *b* and shaft *e* of 21 to 1. Hence, when using the electric starter, there is a total reduction of 12×21, or 252, to 1, between the starting-motor shaft and the shaft *e* coupled to the crank-shaft of the engine. In starting, the one-way ratchet gear *d* is locked by means of pawls operated by the starter switch *e*, Fig. 2. Then the rotation of the pinion *a*, Fig. 3, by the starting motor causes the engine crank-shaft to be rotated.

20. The starting-motor torque is about 12 foot-pounds, and is capable of turning the motor 25 to 50 times per minute through the reduction gear. When the engine starts under its own power, the pawls ride on the ratchet teeth until lifted out of contact with the ratchet gear by the releasing of the starting switch. The unit then revolves as a flywheel, eliminating the necessity of the engaging or disengaging of gears or other driving mechanism. The motor shaft does not rotate because the gear *b* does not turn. When the hand crank is used on the end of the shaft *c*, there is a ratio of 21 to 1 between this shaft and the engine driving shaft *e*, the reduction gears between gears *a* and *b* not being available in this case.

The gear *f* has no effect on the operation of the starting unit, but is provided for driving accessories, which may be mounted in place of the plate *f*, Fig. 2. An electric generator, machine-gun synchronizer, or other device may thus be driven from the crank-shaft of the engine. By attaching a generator

to the casing *b,* Fig. 2, current can be supplied for recharging the storage battery as well as for lights and wireless service. The unit thus forms a complete electric generating and starting system weighing less than 29 pounds.

21. Bijur Starter.—Another type of electric starter is shown in Fig. 4, being attached in this case to a Liberty engine. In addition to details of construction, this starter differs from

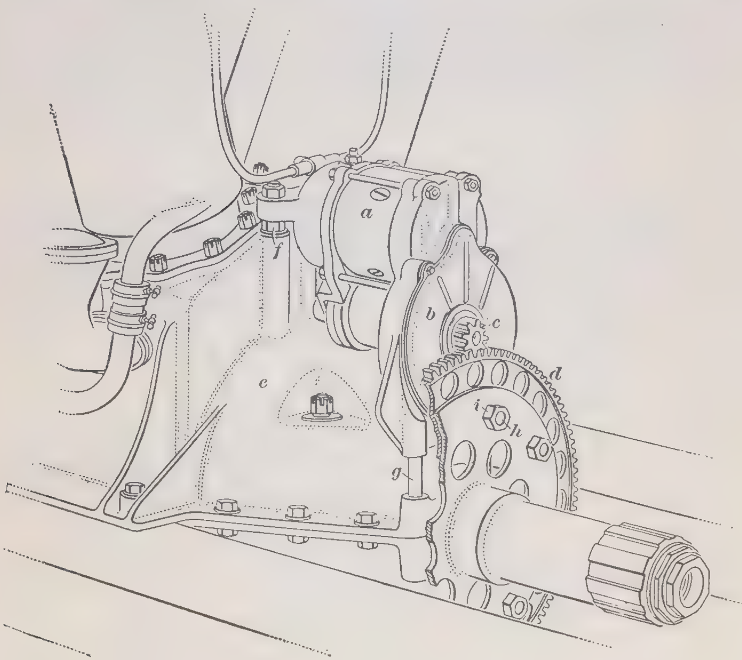


FIG. 4

the one just described in that it is applied at the propeller end of the engine, and is not in permanent connection with the engine. The starter consists of an electric motor *a,* the shaft of which carries a pinion that meshes with a large gear inside the casing *b.* On the same shaft with the large gear is a pinion *c* that engages with or disengages from a ring gear *d* which is bolted to the hub of the propeller. This reduction, and the relative directions of rotation of the four gears in mesh, are

shown diagrammatically in Fig. 5, *a* representing the gear on the end of the starting-motor shaft, and *d* the ring gear on the propeller. The pinion *c*, Fig. 4, is in mesh with the ring gear *d* only when cranking is actually taking place. Its action is entirely automatic, as it is caused to operate by closing the electric starting switch.

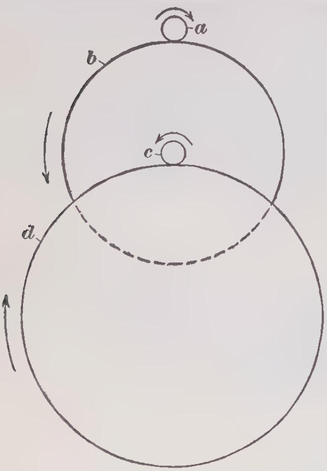


FIG. 5

22. The shifting mechanism is designed to prevent the pinion *c*, Fig. 4, from entering into mesh again with the ring gear *d* when the engine is running or coming to rest. In other words, the design is such that the pinion can mesh with the ring gear only when the starting switch is closed. The principle of operation of the automatic mechanism is illustrated in Fig. 6. The shaft *a* represents the shaft of the starting motor and carries the gear *b*, which meshes with the gear *c*. The gear *c* is mounted on the shaft *d*, which has a helical screw-thread and has a pinion *e* keyed on its outer end. The ring gear that bolts to the hub of the propeller is shown at *f*. The action of the mechanism is as follows: When the starter switch is closed, the gear *b* causes the gear *c* to rotate rapidly. The inertia of the gear *e* causes the screw-shaft *d* to lag behind the gear *c*, with the result that the screw-shaft *d* unscrews from the gear, or, in other words, moves endwise in the direction of the ring gear *f*, until the pinion *e* meshes with the gear *f*. The motor now being connected to the propeller, turns the propeller over at a speed of from 35 to 50 revolutions per minute, until the engine fires and runs under its own

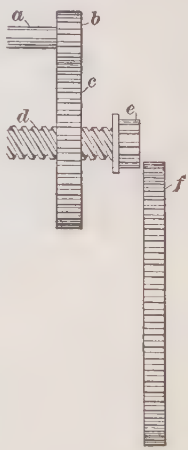


FIG. 6

power. When this takes place the ring gear *f* on the propeller momentarily drives the screw-shaft *d* at a speed greatly in excess of the speed at which it was turning before the engine started to fire, and in the same direction. Consequently, the screw-shaft now rotates more rapidly than the gear *c*, which causes the shaft to screw into the gear *c* and draw the pinion *e* out of mesh with the ring gear *f*. In other words, the action by which the pinion was thrown into mesh with the ring gear is reversed. As soon as the engine fires, the starting switch should be released, after which the starting motor will come to rest. In case, however, the pilot fails to release the switch, the motor merely rotates freely and the pinion will not mesh again with the ring gear.

23. The starter is mounted directly on the crank-case *e*, Fig. 4, being held by two bolts *f* at the rear end, and two extension bolts *g* at the front, just behind the gear *d*. The ring gear *d* is here shown fastened to the flange of the propeller hub by the bolts *h* and the nuts *i*. The propeller and outer hub flange are omitted to show more clearly the starter mounting, but in the actual construction the bolts *h* pass through the propeller and outer hub flange, and the whole is firmly held together by means of the nuts *i*. The current for the starting motor is supplied by a storage battery.

STOPPING

24. When completing a flight, the engine should be slowed down gradually, and allowed to run slowly for two or three minutes, so that the forced circulation of water will cool off the cylinders considerably. The throttle should be closed, after which the magnetos should be short-circuited. Care must be taken to short-circuit both magnetos. If a long flight has been completed, it is good policy to squirt about a tablespoonful of kerosene into each cylinder either through the priming cocks, if any are provided, or through the spark-plug openings. If the engine is started again in a short time and run for five or ten minutes, it will start much easier the next time.

If the engine continues to run in a jerking manner when the ignition is cut off at the switch, the motor is probably overheated, causing ignition of the entering charges. If the engine runs smoothly with the switch closed, it is a good indication that the grounding wire has become disconnected, or the switch fails to make proper contact. The trouble might be caused by the breaker cap being off the magneto, or not on far enough to make contact and complete the grounded circuit.

LUBRICATION

25. The oil used in aeroplane engines should be kept clean and of a quality as uniform as possible. It is common practice to drain all of the oil from the engine at the end of every run of any considerable length, while the engine is still hot, and to allow the oil to settle overnight. The clean oil from the top is then poured off for use again, leaving that part in the bottom of the retainer which has the appearance of being dirty. Enough new oil of the same kind as that already used should be added to make up the required amount. In no case should two different kinds of oil, or oils of different quality, be mixed in the oiling system of an aeroplane engine. The process of using the old oil again should not be continued too long, as the oil is gradually growing poorer, because of what has been burned out of it, or because of the carbon and metal dust that it takes up. It is also thinned out by the gasoline which is not burned and which condenses and works past the pistons into the lubricating oil.

26. No oil other than that specified by the makers should ever be used in new engines, because, in the design of the engine, the bearing clearances and other parts of the oiling system are carefully worked out for a certain grade, weight, and pressure of oil, and the use of an oil which is even a little lighter or heavier than that specified may have considerable effect on the smooth running of the engine. When it is difficult to prevent a surplus of oil from working past the pistons, as may happen when the cylinders become somewhat worn, it

is better to use a heavier oil than to reduce the oil pressure. When this is done, the bearings should be given more clearance because the film of oil in the bearings will be thicker and will need more room. A heavy stationary engine can have bearings of surface large enough so that the oil will not be squeezed out, but aeroplane engines have small bearings in proportion to the work put upon them, and so must depend on the oil pressure to keep a film of oil in the bearings. This should be kept in mind when any change in the oil pressure is being considered.

27. The relief valves may need adjusting frequently in order to maintain the required pressure. This pressure should be correct when the oil is hot. It will be greater when the oil is cold, and will also be greater at high speed than at low speed. The strainers of the oiling system should be cleaned thoroughly at frequent intervals with gasoline and a brush, because even a partial clogging of these strainers may cause a sufficient lowering of the oil pressure to cause serious damage. The oil pipes should be securely held so that they cannot vibrate, as vibration will loosen up the joints. This loosening may sometimes cause leakage, and may eventually result in broken pipes. Whenever hose is used to connect the tubing, the inside of the hose where it comes in contact with the oil must be fabric, and not rubber, for the reason that rubber is soluble in oil. When the oil is drawn out of the oil sump after a long trip, it is a good practice to flush out the sump thoroughly with gasoline. All of the old oil and gasoline must be drained out of the sump before a new supply of oil is provided.

28. The ball bearings and distributor bearings of the magneto must be oiled, but this should be done advisedly, as too much oil will result in the flooding of the magneto, causing very serious ignition troubles. The very best quality of oil must be used for this purpose, and only the actual amount as recommended by the maker. Oil should never be used on the circuit-breaking mechanism. The cam, or cams, in the breaker box should be lubricated by using a very small amount of vaseline, which is wiped off carefully so that only a very thin film is left.

The timer-distributor should be treated in the same manner as the magneto, keeping in mind that with such devices more damage results from overlubrication than from underlubrication.

COLD-WEATHER SUGGESTIONS

29. Anti-Freezing Solutions.—If the engine is to be run during freezing weather, either the water must be drained off every night, or else some agent must be mixed with the cooling water to lower its freezing point. This is not necessary, however, if the aeroplane is properly housed after each flight, and is not allowed to stand in the open air long enough to cool the engine off entirely. Various substances are added

TABLE I

FREEZING POINTS OF MIXTURES OF GLYCERINE AND WATER

Percentage of Glycerine	Percentage of Water	Freezing Point of Mixture Degrees F.
10	90	29 above zero
20	80	21 above zero
30	70	12 above zero
40	60	zero
50	50	15 below zero

to the water to lower its freezing point. The most common substances are wood alcohol, denatured alcohol, calcium chloride, and glycerine, all of which have their advantages and disadvantages. Alcohol vaporizes and passes out of the cooling system more rapidly than water, and hence must be replaced frequently. This is a disadvantage in aëroplane service, as it may not always be convenient to get alcohol when needed. Furthermore, the alcohol lowers the boiling point of the solution.

30. Glycerine and water form a mixture that has a lower freezing point than water alone, but the glycerine is liable to attack the hose connections to the radiator. It is recommended

for aeroplane engine service because the glycerine stays in solution, and as the engine is overhauled at regular intervals, the condition of the hose connections can be easily noted.

TABLE II

FREEZING POINTS OF MIXTURES OF DENATURED ALCOHOL, GLYCERINE, AND WATER

Percentage of Alcohol	Percentage of Glycerine	Percentage of Water	Freezing Point of Mixture. Degrees F.
5	5	90	25 above zero
10	10	80	18 above zero
15	15	70	9 above zero
20	20	60	8 below zero
25	25	50	26 below zero

Glycerine, water, and alcohol make a very satisfactory antifreezing solution. Tables I, II, and III, compiled from experiments made by the United States Bureau of Standards, give the approximate freezing points of various mixtures of wood alcohol, denatured alcohol, glycerine, and water. These experiments were made with ordinary commercial grades of wood alcohol, denatured alcohol, and glycerine.

TABLE III

FREEZING POINTS OF MIXTURES OF WOOD ALCOHOL GLYCERINE, AND WATER

Percentage of Alcohol	Percentage of Glycerine	Percentage of Water	Freezing Point of Mixture. Degrees F.
5	5	90	25 above zero
10	10	80	16 above zero
15	15	70	5 above zero
20	20	60	11 below zero
25	25	50	31 below zero

31. Making Starting Easier.—In order to make the engine start more easily when it is to stand all night, it is

advisable to inject a little kerosene into the cylinders through the petcocks, when these are provided, while the engine is still hot after the previous run. When starting the engine again, the cooling system should be filled with hot water, and it is a good practice to prime the engine by squirting gasoline through the petcocks, and turning the propeller over a couple of times. The choke of the carbureter should be closed while the engine is being turned over, so that a rich mixture will be drawn into the cylinders.

In very cold weather, it is a good plan to run the engine for three or four minutes, and then stop it for a little while, to give the heat a chance to communicate to all parts of the engine and thin the oil properly, before the engine is put under full load.

Some makers recommend that all oil, as well as water, be drained from the engine before it has had an opportunity to cool off. Hot lubricating oil should then be placed in the engine when it is to be started again, which will assure a more speedy action of the lubricant.

INSPECTION OF ENGINE

32. There are certain details that should be followed after each long flight or several hours of sustained operation. A new engine should not be run for more than 5 hours without draining out the old oil from the oil reservoir, and cleaning the oil strainer. This same procedure should be carried out at the end of the second 5-hour period of operation, and then at the end of the next 10 hours. Each spark plug should be removed and cleaned with gasoline, and the width of the spark gap tested and set to the gauge.

DISTRIBUTOR

33. The distributor head should be removed and wiped off carefully. A carbon brush is pressed against the cover, or housing, by a light spring. As this brush wears, it leaves a

deposit of carbon dust which must be removed with a soft cloth moistened with gasoline. Another cloth containing a very little vaseline should be rubbed over the surface to oil it, but after this is done, the inner surface is wiped practically clean. If, for any reason, the distributor connections are removed, care must be taken to connect the terminals up again properly. The rotating brush must be connected with the terminal leading to the spark plug of the cylinder which is about to fire. The firing order of an engine is usually marked on the distributor terminals, or is found from the maker's instruction book. It should be remembered that No. 1 cylinder is the cylinder nearest the propeller, and the right-hand cylinder is the one at the right hand of a person sitting in the pilot's seat. The distributor brush should be examined, and if broken or worn to such an extent that it is getting short, it should be replaced. The metal surfaces embedded in the distributor head should always show a bright, smooth surface. If scratched, they should be smoothed up, and if burned, the distributor should be replaced.

SYNCHRONIZING OF CIRCUIT-BREAKERS

34. As most aeroplane engines are equipped with two complete ignition systems, and therefore two circuit-breakers, these breakers should be examined to see that they break their respective circuits at exactly the same time. This is called *synchronizing* the circuit-breakers. Sometimes there are two circuit-breakers in each system, and these should be inspected to see that all four begin to open at the same time. This point may be determined by placing tissue paper between the contact points, and noting if they loosen at the same instant. It can also be determined by the use of a battery and test lamps. The lamps, of course, must have the same voltage as the battery. The method of using the lamps is shown diagrammatically in Fig. 7. A wire *a* is run from the terminal *b* of the battery *c* to a lamp *d*, and thence to the circuit-breakers *e* and *f* in one of the ignition systems. Then another wire from the same battery terminal is run to another lamp *g* and to the circuit-

breakers *h* and *i* in the other ignition system. The opposite pole or terminal *j* of the battery and the second terminal of the circuit-breaker should be connected to some part of the engine as a ground, as shown at *k*.

35. It will be seen that when the contact points touch, the lights will burn, and when the contact points are separated, the lights will go out. By turning the propeller slowly forwards, with the switch in the "off" position, and observing the lamps, any variation can be detected. The propeller should be turned through two complete revolutions to test all of the cams. If one or more of the cams are faulty, the cam-shaft should be rejected. The levers are provided with means of adjustment. Where each system has two levers that are intended to open simultaneously, the contact points of one lever can be held apart with a piece of paper while the other lever is being tested. In a system where a third lever operates on the same cam, the third, or auxiliary, lever should open first when the engine turns in a forward direction, the office of the auxiliary lever being to prevent a spark from occurring at the spark plug when the engine is rotated backwards, and thus eliminate the danger of a back kick.

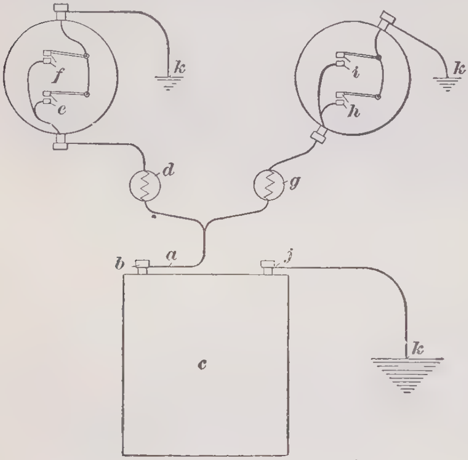


FIG. 7

TESTING MAGNETOS

36. In inspecting a magneto, the first thing to do is to see that the operating parts are free from oil and dirt. The condition of the coil and magnets can then be determined by the

character of the spark that the magneto delivers. The magneto should be fastened to a base and driven from some source that will give a fairly uniform speed. The apparatus for testing the spark need not necessarily be expensive or elaborate. It is best to have as many pairs of terminal points as there are distributor connections in the magneto, with one terminal point connected to a distributor terminal on the magneto in the same manner as a spark plug would be connected. The other terminal is joined to the base of the magneto. The path of the current will then be from the distributor of the magneto to a terminal point, across an air gap to the second terminal point of the pair, and thence back to the base of the magneto.

37. The terminal points may be made of any convenient pieces of solid wire (iron or steel wire would be better than copper) but the ends should be filed to a sharp point, and held so that they are well insulated from each other, thus preventing the current from finding a path easier to escape through than across the intended gap. Clamping them between strips of dry wood fastened to a wooden base will insulate them and hold them in position, which is all that is required. Soft rubber placed between the strips of wood will help both the insulation and the grip on the terminal wire.

38. The terminal wires should either be soldered to the connecting wires or have the surfaces scraped clean and carefully clamped together to insure good contact. The gap between the terminal points should be exactly the same in each pair, and about one-fifth inch, or 5 millimeters, for the high-speed test, unless the makers direct differently. The magneto should be run about 15 to 20 per cent. faster than its normal running speed during a flight, and the spark control placed in full advance so that the breaker points open early. The test should be continued for 3 or 4 hours, so as to make the conditions similar to those of a flight. Toward the end of the run, the spark should be watched steadily for several minutes, to make sure that there is no missing whatever, and also to see that there is no variation in the intensity of the spark; that is, it should not be strong at one time and

weak at another. Considerable sparking at the contact points of the circuit-breaker indicates defective action, probably due to a broken-down condenser.

39. A slow-speed test is sometimes desirable to show whether the spark is strong enough for starting. For this test, the speed of the magneto should not be greater than 150 revolutions per minute, and the spark should jump a gap of not less than one-eighth inch with the breaker lever in the full retard position. If the magneto fails in either of these tests, it should be looked over very carefully for possible loose wire connections, poor brush contact, a sticking breaker, a weak breaker-lever spring, or some part not properly cleaned. If this examination fails to disclose the defective part, it is advisable to return the magneto to the makers, or to one of their regular service stations, for repair.

The distance between the breaker points should be adjusted before the magneto is tested. The correct distance is as follows: Dixie magnetos, .45 to .55 mm., or .018 to .022 inch; Berling magnetos, .4 to .5 mm., or .016 to .02 inch; Bosch magnetos, .35 to .45 mm., or .014 to .018 inch.

AVIATION STORAGE BATTERIES

40. Construction.—A storage battery constructed especially for use with a timer-distributor ignition system in aviation engines is shown in cross-section in Fig. 8. It consists of the usual hard-rubber jar, plates, separators, vent plugs, terminals, etc., as described in a preceding Section, in connection with the more common type of lead-plate storage battery. The two differ somewhat, however, in the details of construction. The aviation battery has four cells and is of very light construction, and because of its extended vent plugs *a* can be turned upside down without spilling any of its electrolyte. This is a valuable characteristic in aviation service, as in various aeroplane maneuvers the machine is turned completely over, and in some cases is actually flown upside down. Because of the small amount of electrolyte that the battery

carries, special attention is required to insure that the electrolyte will be of the proper amount and density at all times.

41. After each long trip, or at least once a week, the battery should be flushed by removing the vent plug *a*, Fig. 8, and filling each cell with distilled water to a height of 1 inch above the baffle plate *b*, using a bulb syringe of the form illustrated in Fig. 9 for this purpose. A very handy method of determining the height of the liquid is by using a glass tube. The tube is inserted in the vent opening at the top of the cell, and allowed to rest on the baffle plate. A finger is placed tightly over the end of the tube as shown in Fig. 10, and the tube withdrawn from the cell. The depth of the liquid in the cell above the baffle plate is indicated by the height of the water column in the tube, and this depth must be increased or decreased by adding or removing distilled water until it is exactly 1 inch above the baffle plate.

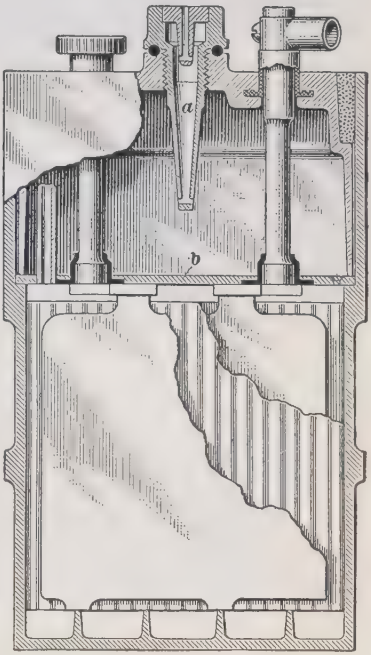


Fig. 8

42. The water should be allowed to stand for from 2 to 5 minutes, after which it should be drawn off with the syringe, down to the plate *b*, Fig. 8. After all surplus water has been removed carefully, the acid and the water must be given time enough to mix thoroughly and then hydrometer readings are taken to determine the specific gravity of the electrolyte. To do this, the battery is tipped over on its side, and a special hydrometer as illustrated at *a*, Fig. 11, is used to test the specific gravity. The hydrometer syringe has a hard-rubber tube *b* bent so as to reach to the inner wall of the cell,

which, of course, will be the bottom when the battery is on its side. If the battery is in a discharged condition, it should be put on charge at 1 ampere and charged until the terminal voltage, with this current flowing, has risen to a maximum, or, in other words, has shown no rise for a period of an hour. The vent plug should be out while the charging is in progress.

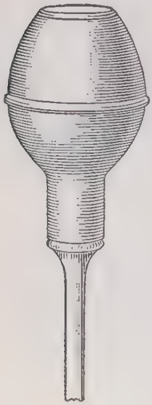


FIG. 9

43. The specific gravity of a fully charged battery is between 1.290 and 1.310. If the hydrometer shows the specific gravity to be greater or less than this after the battery has been charged, the battery should be held upside down for 5 or 6 minutes, and the electrolyte allowed to drain out into a rubber or a glass jar. An old battery jar that does not leak will serve this purpose very well. The specific gravity of the electrolyte should then be adjusted by adding 1.400 acid or distilled water, as conditions require, until the specific gravity is brought to the proper point. This electrolyte should be poured into each cell to a depth of 1 inch above the plate *b*, Fig. 8. The battery should be allowed to stand from 5 to 10 minutes (not over 10 minutes), after which the surplus electrolyte is drawn off with the bulb syringe, the battery remaining in an upright position.

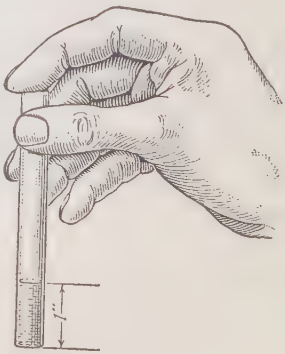


FIG. 10

44. Preparing New Battery for Service.—Aviation batteries are sent out from the factory bone dry, which means that no acid has ever been put into the cells. When placing a new battery in commission, the battery is taken from the paper carton, and the vent plugs are removed. After this each cell is filled with electrolyte having a specific gravity of 1.255, to a depth of 1 inch above the baffle plate *b*, Fig. 8. This electrolyte should be prepared in a non-metallic vessel,

and is formed by, approximately, one part of chemically pure sulphuric acid (1.835 specific gravity), and three parts of distilled water by volume. The sulphuric acid usually sold in drug stores is not suitable for use in storage batteries, because of its impurities.

45. In preparing the electrolyte, the acid should be poured slowly into the water. *The water should never be poured into the acid* as heat is thus produced so rapidly that the acid will boil and splash. After the battery has stood for 15 minutes, the depth of the electrolyte above the baffle plate is measured by means of the glass tube referred to in Art. **41**, and if it is not 1 inch above the plate, additional electrolyte should be poured into the cell. The battery should then be allowed to cool for 8 hours, after which it is charged with a current of 7 amperes for 70 hours. Following the completion of this charge, the battery is tested by discharging it for about 15 seconds at 20 amperes, and the voltage of the cells tested during the discharge. If each one tests 1.55 volts, or over, at 80° F., the battery is fully charged. The battery should be allowed to stand for 15 minutes, and then the surplus electrolyte is drawn off from the cells until it is down to the baffle plate, the battery being in an upright position. The battery is now ready for service. None of these details should be omitted, or done carelessly, as the efficiency of the battery will be lowered.

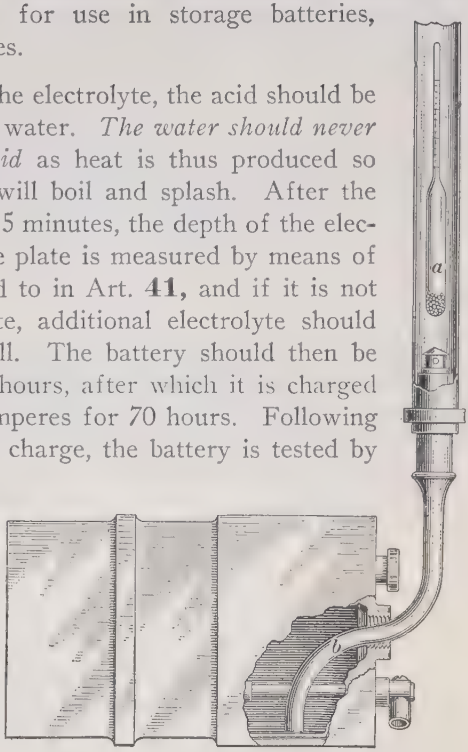


FIG. 11

GASOLINE SYSTEM

46. The entire gasoline line should be looked over carefully, and all piping and connections examined for leaks. If the gasoline is fed to the carbureter by gravity, the air vent in the tank must be freed from dirt or other obstacle that may have lodged in it. Gasoline cannot flow freely from the tank unless there is an opening from the outside air to the space above the gasoline in the tank. It is well to draw off the gasoline from the bowl of the carbureter through the drain cock to remove any sediment or water that may have accumulated there. The jet, or jets, should be examined to see whether any deposit has collected on them, which would tend to lessen their capacity, and the strainers, wherever they are located, removed and cleaned by pouring boiling water through them in a direction opposite to that in which the gasoline was passing on its way to the carbureter.

47. All joints in the intake manifold should be examined for air leaks by placing oil around the joint and noting whether it is sucked into the joint when the engine is turned over. A slight leak will often cause an unequal mixture in the different cylinders and result in uneven firing of the engine. It is of great importance, also, that the carbureter, or carbureters, be so adjusted that each set of cylinders will receive exactly the same amount of fuel, so that the same force may be developed in all of the cylinders, and thus prevent vibration. It must not be assumed, however, that the carbureter is at fault whenever the engine does not run properly. As a matter of fact, if the carbureter were adjusted properly originally, it would not readily be thrown out of adjustment, unless one or more of the adjusting devices worked loose. Generally, the defective running of the engine can be traced to some other source.

48. If the engine is missing or running irregularly, and the indications point rather strongly to poor carbureter adjustment, a simple expedient will serve to indicate whether or not the trouble is located at this point. If the carbureter is of the

auxiliary air-valve type, the auxiliary valve should be held off its seat when the engine is running at the speed at which it is giving trouble, thus weakening the mixture. If this does not remedy the trouble, the main air intake should be partly obstructed by holding a hand over it, thus enriching the mixture. If neither of these experiments corrects the faulty action, the trouble is positively not in the carbureter adjustment. Even if the action of the engine is improved by weakening or increasing the air supply, other causes that might contribute to the trouble should be investigated before any change is made in the adjustment itself.

49. The improved condition brought about by raising the air valve, thus thinning the mixture, might indicate the presence of some foreign substance under the needle valve, allowing the gasoline to rise too high in the float chamber. If enriching the air supply by obstructing the air intake improves the running of the engine, it shows that the mixture was too weak, and this might be caused either by air leaks in the intake manifold, a closed air vent in the tank, a partly clogged feedpipe leading from the tank to the carbureter, or dirt in the spray nozzle, etc.

If the mechanic making the inspection is satisfied that the carbureter is out of adjustment, the readjusting should be done by one thoroughly competent in this work, and should be made strictly according to the instructions. A lost or damaged instruction pamphlet will be replaced by the maker of the carbureter on request. In making inquiries of the manufacturers concerning a carbureter, it is advisable to specify the name and the model. After an adjustment has been made, all adjusting screws must be tightened up or held in some way, so that there is no possibility of their jarring loose and changing the adjustment of the carbureter when the engine is in the air.

GENERAL INSPECTION

50. It is advisable to go over the entire mechanism in almost the same manner as described in connection with a new engine. The valves should be inspected for proper clearance and weak

or broken valve springs, and the compression tested to see if the valves are seating tightly. It should be seen that the propeller is tight on the shaft, as the entire output of the engine is transmitted through the propeller when driving the aeroplane through the air. It is, therefore, of the utmost importance that the propeller be tight on its shaft and locked firmly in place.

Every bolt, nut, or screw should be examined and tightened wherever necessary. The cylinder-head bolts in engines of the removable-head type frequently work loose when the engine is hot, and must be drawn up before the engine is started again. The engine-bed bolts also should be given attention and all water connections should be examined to see that they are tight, and that there is no leakage. The piping should be held so that it cannot swing or chafe against another part.

This inspection should be carried on carefully and thoroughly, keeping in mind the importance of the perfect operation of each individual part if the engine is to do its work most efficiently, and with the greatest degree of safety to the one who is to operate the aeroplane.

OVERHAULING THE ENGINE

DISASSEMBLING

51. After an engine has been engaged for a specified number of hours in actual flight, it should be removed from the aeroplane body, or fuselage, taken apart, and carefully inspected and adjusted. The length of time that the engine should be run before being disassembled differs according to the recommendations of the individual manufacturers. An engine can be run a greater number of actual flying hours without danger, if the service is periodical rather than in long, sustained flights. For instance, the strain on an engine in a continuous flight of 24 hours will be greater than the same actual flying time distributed over several short flights. It is generally accepted that the safest plan is to overhaul the engine after it has run for 50 hours.

52. In overhauling the engine, a definitely planned and systematic method should be followed, so that no part may pass uninspected, small pieces mislaid, or the ordering of new parts neglected. The plan most in favor is to obtain as early as practicable a list of all the new parts that will be needed, so that they may be ordered promptly, and any delay in placing the engine back in commission avoided. The tearing down of the engine should be carried on as rapidly as is consistent with good work, but in all cases sufficient time must be allowed for the thorough cleaning and careful inspection of each part as it is removed. When the group is reassembled, it must be done systematically so that no small pieces of the engine may be mislaid or lost. It is especially important that the marks on the timing gears should be located and understood. The looseness of the bearings should also be noted before disturbing them, and the shims and liners of the bearings kept in place. The nuts in the more important places should be replaced on their individual studs, and the piston rings replaced in the same order, with the same sides up.

53. Most of the tools required in the overhauling process are furnished with the engine. Any other wrenches or screw-drivers obtained for this work must fit properly, so that the nuts and screws will not be injured by their use. Open-end wrenches should have narrow or slim jaws, so as to work in places where a blunt-ended wrench would not have room to turn. They must be of high-grade material to give the required strength to the jaws of the wrench. Pliers, oilers, cotter-puller, hammer, scrapers, vise, etc., are necessary, as well as instruments for accurate measuring; and kerosene and a brush for cleaning the parts. Cloth is better than waste for wiping, because it leaves less lint. Plenty of bench room should be provided where the smaller parts may be laid in their proper order. A large box with several partitions should be close at hand on the floor for the larger parts, such as cylinders, connecting-rods, etc. The parts for each cylinder should be kept together in one space of the box. A convenient support for the engine can be made by using two strips of strong

wood about 2 inches by 4 inches, and long enough so that they may rest on frames at each end of the engine. The engine is bolted to these, as it would be to the fuselage, and the frame must be high enough so that no part of the engine will strike the floor when it is turned bottom side up. If the ends of the strips are rounded, they will be easier to handle.

54. The propeller is removed from the hub, but the hub must not be removed from the crank-shaft. The water, gasoline, and exhaust pipes, the control rods, wires, and other parts attached to the fuselage are disconnected, and the radiator removed. The rope sling used in lifting the engine from its bed should be so placed that it cannot slip or press against any light parts to break or bend such parts, and it should be adjusted so that the engine will balance in the sling. The wires of the ignition system can generally be removed as a unit by removing the brackets which hold them, and then disconnecting the wires at the spark plugs and distributor. If magnetos are used, and they are suspected of not being in perfect condition, they should be examined and tested as early as possible so that time may be allowed for sending them to the factory for whatever repairs may be necessary.

55. It is well to note the valve clearances before disturbing the valves because an unusually wide gap indicates that the adjustment is insecure or that some part involved is wearing faster than it should. This is caused usually by insufficient oil or by the part not being properly hardened. An examination will reveal the places that require special attention. As the parts are removed they should be placed on the floor or bench in the order in which they are to be reassembled, and given identifying marks, if they are not already marked by the makers. These marks will enable the mechanician to assemble the parts in the proper places and right end first, if there is a possibility, as in the case of bearing caps, of turning them the wrong way. Marking the parts by stamping numbers on them with steel figures is the method preferred by many mechanics for parts that are not hardened. Small pasteboard tags marked in such a way as to be readily understood by the

mechanic are attached to the hardened parts. Envelopes, open at the end, are convenient for very small pieces. The envelopes are kept in boxes of a size small enough so that they cannot lie down flat and thus spill or mix their contents.

56. Where an examination only is to be made, the cylinders are generally removed without taking the engine out of the fuselage. This permits an inspection of the condition of most of the important parts, the grinding of the valves, and the scraping out of the carbon that has been deposited on the walls of the combustion chamber. As the cylinder is slipped off from the piston, the latter is liable to be sprung or cracked if not held with the hand so that it cannot swing down suddenly. The connecting-rods should be examined closely for any indication of cracks or flaws that might later cause them to break, and the play in the crank bearing should be noted. In some engines it is possible to remove the pistons through the bottom of the engine by removing the lower part of the crank-case and taking off the connecting-rod cap, without disturbing the cylinders or top part of the engine. It should not be necessary to remove the piston in this way unless a piston ring should break or stick in its groove soon after the periodical inspection.

57. When the cylinders are removed, they should first be examined for score marks or scratches in the surface of the inner walls, where the piston travels. If these score marks are too deep to be removed by lapping, the cylinder should be discarded at once. Next, search for signs of cracks in the flange that holds the cylinder to the crank-case. If any serious cracking has developed, this is a sufficient reason for rejecting the cylinder. The water-jacket should be tested for possible leaks by using an air pressure ranging from 10 to 20 pounds, connecting the air hose to one water connection, and plugging the other, and submerging the cylinder in water. If there are leaks, they can usually be remedied by an expert repairman who has the necessary equipment.

58. When the cylinders are removed, care should be taken to note whether one cylinder has more carbon in it than another,

as this will indicate whether the oiling is uniform or not. It is assumed that the oiling is uniform when the engine is new, and if on inspection it is found to be not uniform, the probable cause of the trouble is an obstructed oil passage. If an examination shows that the oil passage, strainers, and pump are in perfect condition, and no means of adjustment is provided in the design of the engine for regulating the supply of oil to each individual cylinder, the oil pressure may be increased, as it is delivered from the pump, by adjustment of the relief valve, until the cylinder having the least carbon receives oil enough to prevent scoring. Steps should then be taken to equalize the flow of oil to the cylinders.

The valves should be tested for gas-tightness, which can be done best by turning the cylinder upside down with the valves in place and pouring a small quantity of gasoline into the cylinder. If any leakage is indicated by the seepage of gasoline around the valves, the valves should be removed and ground in place.

59. Before removing the cam-shaft, the gears should be examined to see if they run together properly. If much looseness is in evidence, this should be noted, so that the proper adjustment can be made when reassembling the engine. The clearance of a gear is the distance between the end of the gear tooth and the bottom of the corresponding space in which it meshes, and should be about one-twentieth of the length of the tooth. Gaskets should be examined when they are removed, and in most cases it is advisable to replace them with new ones when assembling the engine. If this is inconvenient, it is a good plan to scrape the old one clean, and anneal it (if it be of copper-asbestos) before replacing it. The faces against which the gasket rests should be examined and made smooth and flat.

60. If any loose nuts or screws are found, the cause should be investigated and noted. The oil passages and oil grooves in the liners of the connecting-rod bearings and main crank-shaft bearings should be closely examined, and if found not in perfect condition, the liners should be laid aside for

correction. It is very important that all oil passages should not only be kept clean, but that the grooves be of the same capacity as when new, and that the holes leading to the grooves be not obstructed nor the liner shifted so that the hole in it does not line up exactly with the hole in the cap leading to it, in which case the oil supply would be partly cut off from the bearing.

61. The bearings at both ends of the connecting-rod must be true with each other. They must not only be parallel, but must be in the same plane. A good way of testing them is

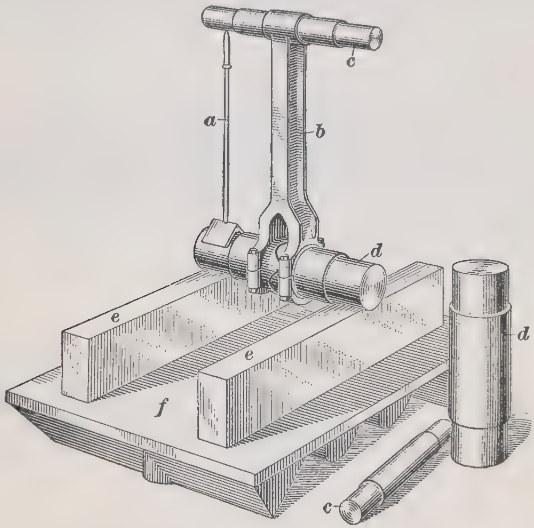


Fig. 12

to make two arbors, one fitting the crank end and the other the wristpin or piston-pin end of the connecting-rod. The two ends of each arbor must be of the same size, and the distance between the ends of the two arbors must then be measured to see whether they are the same distance apart. This can be done by means of an adjustable gauge of the type illustrated at *a*, Fig. 12. The connecting-rod *b*, with its arbors *c* and *d*, is then laid on two parallels *e* resting on a flat plate *f*, to see whether there is any twist in the connecting-rod. The connecting-rod may, if necessary, be bent sidewise or

twisted cold until the arbors are true with each other. If the rod is bent very badly, a new one should be used in its place. Heat should not be employed to assist in the bending.

62. After the connecting-rod is assembled on the crank-shaft, and before the piston is added, it may be necessary to bend it slightly one way or the other near the lower end to bring the wristpin end to the exact center of the cylinder, the upper end being bent an equal amount to bring the pins into line. After it is bent the pins must again be tested as before. A final test can be made after the connecting-rod and piston have been assembled by placing a square against the side of the piston and squaring with the surface of the crank-case, and also measuring to see whether the piston stands exactly central with the opening in the crank-case.

When the crank-shaft is removed, all its bearing surfaces should be examined carefully, measured for roundness by means of a micrometer, and if found scored or out of round, they should be trued up. The ball thrust bearing must be examined for wear, but will not need to be removed unless it is damaged or the end play is excessive.

While the engine is disassembled, it is a good plan to take the carbureter apart, and clean out the fuel jet or jets, gas passages, strainers, etc. This can usually be accomplished by blowing through the carbureter with compressed air.

REASSEMBLING

63. After the engine has been taken apart and each individual part examined carefully for wear, breakage, or improper adjustment, the causes of any such defects investigated and remedied by adjustment or replacement, and all parts cleaned thoroughly, the engine is ready for reassembling. In the process of reassembling, the marks previously made on the various parts should be followed carefully so that each will go in its proper place, and in the proper manner. In connection with gears, bearings, etc., in which looseness was noticed, care should be taken to have just the required amount of play, or

clearance, when they are reassembled. As each part is placed in position, it should be lubricated thoroughly, so that there will be no danger of undue friction or wear when the engine is running, and before the oil can reach the parts through the regular channels.

64. The bolts or nuts on bearing caps, cover plates, cylinder heads, etc., must be tightened uniformly to prevent breakage and to insure tight joints, as well as to prevent undue friction in the case of the bearing caps. All keys or pins must be driven in firmly, and it is best to lubricate them first, so that they will drive easier. This lubrication also insures their easy removal in the future.

If it is necessary to install one or more new cylinders, extreme care must be exercised in their installation. In fitting a new cylinder, the holding-down bolts of all the cylinders must be just hand-tight, and the new cylinder fitted to its place without binding.

65. It may be necessary to file out the holding-down stud bosses a trifle to have the cylinder line up all around and make a perfect fit in the crank-case. In case the holding-down boss does not line up horizontally with the adjacent cylinder holding-down stud boss, a facing cutter should be used to bring it down to position. The holding-down studs should be tightened uniformly on all the cylinders, care being taken that the pressure applied is not sufficient to break the boss away from the thin cylinder wall. This method of tightening down the studs must be followed in replacing the cylinders of an engine even when no new ones are installed.

66. Before placing the cylinder over the piston, the piston should be placed in its upper dead-center position, and its outer surface, as well as the inner walls of the cylinder, lubricated generously. Care must be taken to place the piston on its own connecting-rod, and install it in the cylinder from which it was removed. As stated before, the piston rings should be reassembled in the same order, and with the same end up, as when they were removed, and the openings between the ends spaced equidistantly. It is a good plan to coat the threads of

the cylinder retaining studs, as well as the exhaust-manifold studs, with a mixture of graphite and oil, to provide for their easier removal when they must be taken out again. When the cylinders are in place, it is advisable to screw loose-fitting wooden plugs into the spark-plug openings, to prevent dirt or small parts from falling into the cylinders.

In reassembling the intake and exhaust manifolds, water connections, carbureter, etc., the gaskets must be in good condition. If they are hard or flattened out, it is better to use new ones to insure tight joints.

67. All bolts should be embedded solidly in their proper positions. It may occasionally happen that the bolt or nut is tight, even though it is not down all the way. This is due to burrs or dirt under the bolt head or nut. Consequently, when the engine has been run for some time, the burr flattens out, or the dirt disappears, thus causing the bolts to loosen.

Locking washers, check-nuts, split pins, or other locking devices should always be used, especially on parts that move or are subjected to heavy loads. Lock washers should never be used under connecting-rod cap nuts or main bearing nuts, because they are liable to break and leave the nuts loose. It is best to use castellated nuts pinned firmly in place. In no case should a nut be backed off to make it line up with the opening in the stud. If it cannot be drawn up to this extent without damage, a solid washer of the proper thickness should be placed under the nut so that the holes will just register, when the nut is tightened up properly, or a new nut should be used.

VALVE TIMING

68. There is considerable difference of opinion among automotive engineers as to what constitutes the proper timing of the valves of aeroplane engines. To this diversity of opinion is added the fact that certain factors enter into the design of different engines, making the use of the same valve timing impracticable. For these reasons, no rules that will apply to all cases can be laid down, and the only safe method of pro-

cedure is to follow in detail the instructions sent out for the particular engine at hand.

In order to time the valves of an engine, it is necessary to locate definitely the dead-center positions of the crank, as all measurements are made from these points. It is customary to supply a flat circular disk, called a *timing disk,* as part of the equipment of an aeroplane engine. This disk is so designed that it may be mounted permanently on the propeller hub, or kept on hand as a means of checking the setting of the valves and ignition apparatus. In the absence of a timing disk, the timing marks may be placed directly on the propeller flange.

69. The timing disk must be mounted so that the locating holes, with which it is provided, will fit over the projections made for them. When the disk is in place, the dead-center position must be located. A handy method of doing this is to remove a priming cock or spark plug from cylinder No. 1, either right or left, if the engine is of the **V** type, and insert a pencil, scale, or other object through the opening in the cylinder until it rests on the top of the piston. The object must be long enough so as not to fall into the cylinder, and should be held in one place on the piston in order to obtain accurate results. The engine is then turned slowly over until the piston moves the pencil up as far as it will go, and this will be approximately the dead-center position. At this stage of the operation, a fixed point must be determined on the engine, which can be done by clamping onto the engine a tin pointer or pointers, which, as in the case of the timing disk, usually forms a part of the regular equipment of the engine. A ready means of attaching is to remove one or more of the cylinder-flange nuts, slip the pointer over the bolts, and replace the nuts.

70. With the fixed point properly determined, a mark should be cut in the pencil about three-fourths of an inch above the upper edge of the priming-cock or spark-plug opening, and the engine turned slowly until this mark is just in line with the top edge of the hole. A mark is then made on the disk with a piece of chalk or a pencil, directly in line with one of the points, of which there will be two if the engine is of the **V** type.

The engine is then turned in the opposite direction until the pencil has moved up to its limit, and then down again until the mark on the pencil is again even with the top edge of the opening in the cylinder. The disk should be marked once more directly in line with the pointer, and by taking a point exactly half way between the two points on the disk, the exact dead center will be located. This gives the upper dead center, and the lower dead center is directly opposite, or 180° from this point. Having located these positions, the distances indicated on the timing diagram should be laid off from the dead-center points, so that these lines correspond exactly to the engine timing.

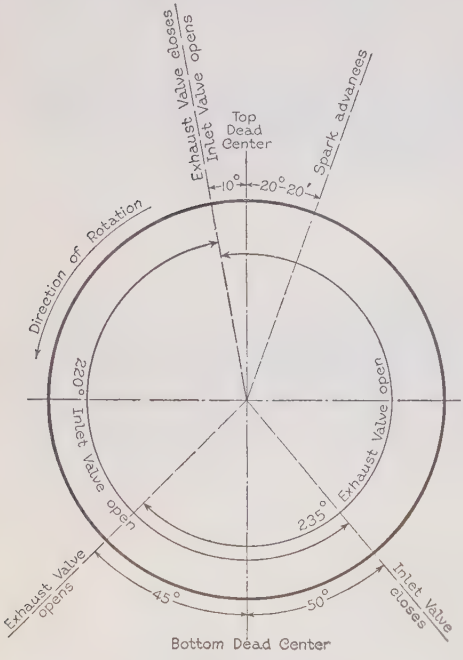


Fig. 13

71. A typical timing diagram is shown in Fig. 13. According to this diagram, the inlet valve of the engine opens 10° after the upper dead center and closes 50° after the bottom dead center, and the exhaust valve opens 45° before the lower dead center and closes 10° after the upper dead center. These measurements in degrees can be very easily changed to inches by dividing the circumference of the timing disk in inches by 360. The result will be the fraction of an inch equal to 1 degree. In some cases, the time of opening and closing of the valves is given in fractions of an inch of piston travel, and in such cases all that is necessary is to insert a scale into the cylinder opening so as to rest on top of the

piston. Suppose the diagram or instruction book shows that the exhaust valve should close $\frac{1}{32}$ inch beyond top dead center. The crank-shaft should then be turned in the normal direction of rotation until the piston has traveled $\frac{1}{32}$ inch as measured by the scale. In timing valves, the engine must always be turned in the direction in which it is to rotate when running.

72. After the cam-shaft gear has been meshed with the cam-shaft, the opening and closing of the inlet and exhaust valves, as indicated on the timing diagram, should be checked. Thus, when the mark representing the time of opening of the exhaust valve in cylinder No. 1 is directly in line with the pointer, the exhaust-valve cam of cylinder No. 1 should be in such a position that any further turning will begin to raise the exhaust lever. Similarly, if the mark indicating the closing of the inlet valve of cylinder No. 1 is in line with the pointer, the inlet cam for this cylinder should be in the position where it has just allowed the inlet valve to close, the tappet gap being of the proper width. If it is found that the valves are late or early in opening and closing, the number of degrees should be noted, and the cam-shaft gear moved a number of degrees corresponding to the lateness or earliness of the valve, without moving the cam-shaft.

73. In **V**-type engines, the two cylinder blocks must be timed separately, keeping in mind the firing order of the engine while doing so. Thus, if the engine is of the eight-cylinder **V**-type, with a firing order 1 Left–4 Right–2 Left–3 Right –4 Left–1 Right–3 Left–2 Right, cylinder 4 Right intakes after 1 Left, 3 Right after 2 Left, and so on.

It is very important that the valve clearance, as recommended for each individual engine, be adjusted before timing the valves, because a small variation in the clearance results in a large variation in the valve timing. If the valves are timed without adjusting the clearance, and then the adjustment is made, the timing of the valves will not be correct.

TIMING THE IGNITION

74. Timing the Magneto.—In timing a magneto, the crank-shaft must be placed in the position where the spark is to occur, and the rotor, or brush, of the distributor placed in contact with the stationary segment that is to be connected to the spark plug of cylinder No. 1, No. 1 being usually assigned to the cylinder nearest the propeller. Then the circuit-breaker is placed at the point where the spark is about to occur, and the magneto is coupled to the engine. As in the case of the valves, the time for the spark to occur varies in different engines, and the recommendations of the maker should be followed in this respect. Because of the fact that aeroplane engines run most of the time with the spark in the fully advanced position, it is generally the custom to time the ignition fully advanced, but this is not always recommended, and care must be taken to follow out the maker's instructions in this respect also.

75. Any cylinder in the engine may be considered as the starting point in timing the ignition, but the general practice is to use cylinder No. 1. The crank-shaft is turned over slowly until the piston in cylinder No. 1 is in its dead-center position at the top of the compression stroke. This point can be determined by watching the inlet valve of this cylinder. After it closes, the crank-shaft is rotated in the direction in which it runs normally until the upper dead-center mark on the timing disk or propeller flange is directly in line with the fixed pointer. The instructions of the maker should now be consulted to find out the exact point at which the spark is to occur, and whether it is to be fully advanced or fully retarded, and the crank-shaft turned until this position as laid off on the disk is opposite the pointer. Thus, if the spark is to occur, say 20° 20′ before the top dead center in the fully advanced position, as indicated in Fig. 13, this distance should be carefully measured on the timing disk, or propeller flange, and the engine turned backwards so as to bring this mark in line with the fixed point.

76. The magneto armature should next be rotated in its normal running direction until the distributor brush makes contact with the stationary segment to which the cable marked No. 1 is connected. Frequently this position is indicated by a figure 1 appearing at a little window in the distributor cover. If no such guiding mark is provided, the distributor cover must be removed. The next step in the timing operation is to place the cam cover in the fully advanced position, which is located by rotating it in a direction opposite to that in which the armature rotates, until it strikes the stop, and the cover is then removed. The armature should be carefully rotated a few degrees in one direction or the other until the contact points of the circuit-breaker are just at the point of separation, as indicated by the position of the actuating cam. The armature should then be coupled to the engine, thus completing the timing.

77. In many cases, the spark timing is given in inches of piston travel instead of degrees of crank-shaft rotation. For instance, the maker of a certain magneto recommends that the spark be timed so as to occur $\frac{1}{16}$ inch before the end of the compression stroke, with the spark in the fully retarded position. In this case, the piston in cylinder No. 1 should be placed at the top of the compression stroke, as explained before, and the crank-shaft turned backwards until the piston has moved down a distance of $\frac{1}{16}$ inch, as measured by a scale inserted in a hole in the top of the cylinder. The circuit-breaker and distributor are then set as previously described, but the cam housing must be placed in its fully retarded position, which is located by rotating the housing as far as it will go in the same direction as the armature rotates.

78. Timing the Distributor.—The ignition system of the Liberty engine has two distributors, and care must be taken to get them on their proper housings when reassembling the engine. The distributors are marked *R* and *L* on the outside surface of the spark-control arms, and should be fastened temporarily by means of two bolts in such a position that the notch on each distributor flange coincides with

the notch on the cam-shaft housing flange. In case it is necessary to replace the old distributors with new ones, without identifying marks, each distributor should be set so that with the spark fully retarded the center line of the cylinders will be exactly half way between *1L* and *6R* terminals. The procedure of timing is as follows:

The spark is placed in the retarded position and the engine is turned over until the piston of cylinder No. 1 left is on its firing point, which is 10° past the top dead center. The two main breakers on each distributor should be checked to see that they both break the circuit at the same instant. If they do not open the circuit simultaneously, or within $1\frac{1}{2}°$ of each other, the breaker-arm bracket assembly should be shifted around, changing the setting of the breaker gap, which should then be adjusted to the proper limits. The operation should be repeated until the two parallel breaker arms open the circuit at the same time.

79. The bolts holding the distributor-base flange should be loosened so that the flange can be rotated in the slotted holes, and with a battery and electric lights connected across the distributor terminals the distributor-base flange is rotated in a counter-clockwise direction until the light just goes out. The distributor should be locked in this position by tightening the holding bolts. This completes the timing for one side, and the right distributor should be set in exactly the same manner, without changing the position of the crank-shaft.

The timing can be checked by turning the crank-shaft backwards, or clockwise, 20° or 30°, and then turning it forwards very slowly, and watching the electric lights. They should both go out at the same time, or within $1\frac{1}{2}°$ of each other. The cross reach rod that operates the timing apparatus should be adjusted so that both distributors are fully retarded, and the timing of the distributors with the spark in the advanced position checked.

80. Connecting Up Spark Plugs.—Care must be taken to wire up the spark plugs to the distributor, whether magneto or timer-distributor is used, so that the sparks will

occur in the different cylinders in the proper order. This order is always included in the instructions sent out by the maker of the engine; but in the absence of such information, the proper order can be determined by observing the order in which the inlet valves open. The cylinders fire in the same order in which they receive the gas through the inlet valves.

TESTING

81. After an engine is overhauled, it should be given a thorough testing out before being installed in an aeroplane. The following description of a test of Liberty engines is typical of common practice. The tests of other engines differ only in certain details, such as the temperature of the cooling water, minimum and maximum speeds, etc.

The engine, with the propeller in place, is placed on a specially constructed test stand arranged so that the propeller tip will clear the ground by at least a foot, and the engine is connected with a cooling system adequate to keep the engine at the proper temperature during the test. Thermometers should be provided in the water passages near the pump inlet and near the engine outlet. The water at the pump inlet should have a temperature of about 150°, and at the engine outlet a temperature of about 185°.

82. An oil reservoir should be connected to the engine, with a thermometer inserted in the line between the oil pump outlet and the reservoir. The thermometer should be located in a temporary oil-sump cover at the propeller end, so that it will extend into the oil collecting in this sump. A control board complete with oil-pressure gauge, tachometer, switches, ammeter, and voltage regulator, should be arranged on the testing stand. With an engine equipped with magneto ignition, the ammeter and voltage regulator would not be included in the equipment.

83. Before attempting to start the engine it should be given a careful inspection to see that all parts are in place, properly secured, and adjustments properly made. The starting pro-

cedure explained in Arts. **11** and **12** should then be followed in starting the engine. After the engine has been started, and while it is warming up properly, the oiling system should be given careful attention. If the proper pressure is not indicated on the oil gauge, or one or more bearings show signs of heating up too quickly, or excessively, the engine must be stopped immediately and the trouble investigated. The engine should be run for at least an hour at a speed of about 1,200 revolutions per minute. If new bearings have been fitted, it is advisable to connect the oil-pump inlet and outlet in such a manner that the oil will pass through a by-pass, and fill the crank-case with a generous supply of oil. The connecting-rods will dip into this oil and insure excessive lubrication during this period.

84. At the expiration of the hour, the by-pass connections should be removed, the oil drained out of the crank-case, and the pump connected with the oil reservoir. The speed of the engine should be increased to 1,400 revolutions per minute, and kept running at this speed for a period of one-half hour. At the end of the half-hour, the throttle should be opened up wide for from 3 to 5 minutes, and the engine speed should rise to about 1,600 revolutions per minute. If the engine holds this speed consistently during the test period, it is considered satisfactory.

The temperature of the oil and water, and the revolutions per minute of the engine, must be observed closely during the test, and a record made of these observations at 15-minute intervals. All oil and water pipes should also be watched for leakage.

If the engine will not hold its speed at certain prolonged throttle openings, it indicates excessive friction caused by improperly adjusted bearings, or improper functioning of the ignition or carburation.

ROTATING-CYLINDER ENGINES

GENERAL

85. The instructions given in Arts. **5** to **8**, in connection with the preliminary inspection of stationary-cylinder engines before starting, apply generally to rotating-cylinder engines as well. The entire engine with its ignition, fuel, and oil systems should be gone over in a thorough, systematic manner. All parts such as bolts, nuts, or screws should be made tight, and all necessary adjustments made, before the engine is declared fit for service. All recommendations and instructions sent out from the factory with each engine should be followed carefully, as no set rules can be laid down that will apply to different engines in all respects. All adjustments should be made with a full knowledge of the reason for such adjustments, and only after a careful investigation of the engine has revealed the necessity for any change at these points.

86. The suggestions covering the disassembling and reassembling of stationary-cylinder engines also apply to rotating-cylinder engines, to the extent that all parts must be properly marked on removal, and given definite locations on the bench or floor, or in special receptacles provided for them, washed thoroughly with gasoline or kerosene and wiped carefully with a soft cloth before being replaced in the engine. The parts must be reassembled according to the identifying marks on them, and exactly as they came out. After reassembling, the valves and ignition must be timed, and the engine tested in practically the same manner as previously explained.

When properly assembled and driven by a careful pilot, the rotating-cylinder engine should run for a long period without attention other than a renewal of the spark plugs or cleaning

of the old ones. After about sixteen hours of actual running at full load, however, it is necessary for the engine to be subjected to a thorough inspection and all worn parts replaced.

GNOME ENGINE

87. Valve Timing.—The valve timing of the Gnome engine differs from conventional rotary cylinder practice, because it has but a single valve, and therefore, the timing will be described in detail. The timing varies slightly in different types of Gnome engines, and each engine is supplied with a special set of timing figures which should be observed.

To time the valves, the engine should be turned in its normal direction of running, and the clearance between the

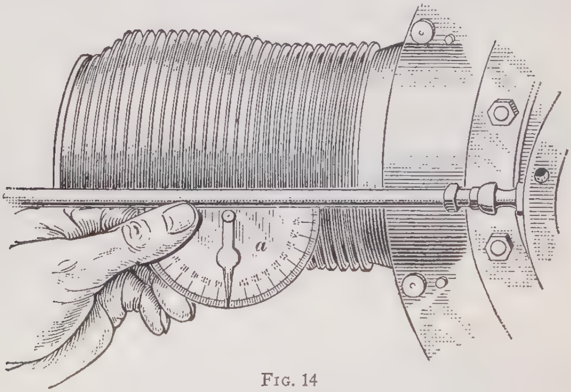


FIG. 14

exhaust-valve lever roller and the exhaust valve adjusted to .5 mm., or .0197 inch, in each cylinder when the valve is closed. The engine is then rotated in the same direction until No. 1 cylinder is 85° past the top dead center, which is nearly horizontal. This angle can be checked by the use of the special timing protractor supplied with the engine, by holding it against the tappet rod as shown at *a*, Fig. 14. The cam-shaft should be turned in a direction opposite to that in which it rotates, or in a clockwise direction, until the cam operating the valve of No. 1 cylinder is just at the point of opening the valve. The engine should be left in this position and the pinions on

the valve gear-case front cover properly located with reference to the cam-gear. This is done by turning the pinions on the front cover until the teeth marked *o* on the two gears point directly toward each other, or are diametrically opposite each other as seen through the ball-bearing opening from the front, as shown in Fig. 15.

88. Without changing either the location of the cam-shaft gear or the pinion gears, otherwise called *satellite gears,* the front cover should be fitted onto the valve gear-case. In order to assist in lining up the bolt holes and gears, it is well to push two rods of about the same size as the bolts through diametrically opposite holes in the cover, and into the holes in the gear-case. The gears must mesh without the least forcing, and when assembled, the setting must be verified by turning the engine over until the marked teeth are diametrically opposite each other, to provide against the breakage that is inevitable if both gears do not mesh with similar teeth simultaneously. When the front cover is in place, it should be secured by the holding bolts, and the ball race fitted in position, after which the engine should be turned over to make sure that there is no binding at any point. The timing is then checked by turning the engine in its direction of rotation, and noting whether the exhaust valve opens 85° past the top dead center and closes 60° before the bottom dead center. It will be well to go over the valve-operating mechanism again and make sure that the tappet clearance is adjusted properly, and that it is the same in all cylinders, in order to insure an even running of all the cylinders of the engine.

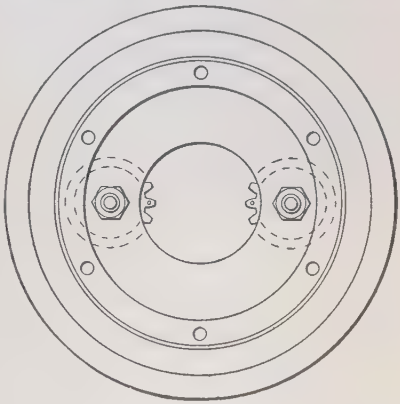


Fig. 15

89. Timing the Ignition.—In timing the ignition of the Gnome engine, which is provided with a magneto, the engine is rotated in its running direction until cylinder No. 1 is 18° in advance of the top vertical center. The angle can be determined by means of the timer protractor shown in Fig. 14. With the cylinder in this position, the armature of the magneto should be turned in its direction of rotation until the points of the contact-breaker are just separating, and the magneto gear is then meshed with the driving gear on the engine. The magneto is then fastened to the main bearing plate. Instead of having the distributor built in the magneto, as is the usual construction, the high-tension collector brush of the magneto connects to a distributor-brush holder carried in the main bearing plate of the engine. The distributor is built in the starting-gear wheel, and consists of a ring of insulating material embedded in the gear, in which are molded brass contact sectors spaced equally and of the same number as there are cylinders. It is necessary for the stationary brush connected to the magneto collector ring to be in contact with the brass segment of the distributor leading to cylinder No. 1, when the magneto and engine are in the relative positions just described.

90. Starting the Engine.—Gnome engines differ somewhat in the method of feeding the gasoline to the engine, and the procedure of starting varies a little with the different systems. When the gasoline is fed to the cylinders by gravity, the engine is started by first turning the engine until a cylinder is at the bottom with the valve open. With the switch in the off position, the gasoline is turned on, and left on until the gasoline begins to run from the open valve, when it is turned off. With the switch still off, the engine should be turned over twice, and it is then ready to start. With the switch on, the gasoline regulating valve is opened, and the propeller is swung over.

When a gasoline pump is provided on the engine, and no hand pump or auxiliary starting supply pipes are fitted, the engine should be primed through the valves in the usual way,

the switch turned on, and the propeller swung over. When auxiliary starting pipes are fitted, the engine is first primed by one or two strokes of the hand pump, the switch is turned on, and the engine is then started, the gasoline being regulated by means of the gasoline regulating valve.

91. When the necessary pressure of the gasoline is obtained by pumping air into the gasoline tank, the engine is started by pumping up pressure in the tank by means of the hand pump, turning on the gasoline so as to prime the cylinders, closing the switch, and turning the engine over. The regulating valve should be adjusted to maintain a pressure of 4 pounds per square inch when the engine is running.

In case the cylinders are flooded when being primed in any of the ways stated, as evidenced by gasoline dripping from the valves, the engine should be turned backwards a couple of times in order to clear the valves of the excess gasoline. Unless this precaution is observed, the superfluous gasoline may ignite in case of a back fire when starting, causing damage to the aeroplane.

92. Stopping.—The engine is stopped by turning off the gasoline supply at the regulating valve, but the switch is left on until after the engine stops, so as to prevent as far as possible the formation of oil deposits on the points of the spark plugs.

LUBRICATION

93. One of the points of the rotating-cylinder engine that requires care different from that of the stationary-cylinder engine, is the lubrication. The centrifugal force set up by the rapidly revolving cylinders tends to increase the amount of oil that works past the piston rings, and leaves a greater amount of carbon deposit in the combustion chamber than in the stationary-cylinder engines. The lubrication problem is made more complex by the fact that the lubricating oil and the gasoline used as fuel are both fed to the engine through the crank-case. This contact of the lubricating oil with the gaso-

line tends to decompose the oil, but vegetable oils are not so easily decomposed by the action of the gasoline as mineral oil. For this reason a good grade of castor oil is generally used, and as the deposit left in the cylinders from castor oil is gummy, and the centrifugal action of the engine causes a large amount of deposit in the cylinders, the revolving-cylinder type of engine requires more frequent cleaning than the stationary-cylinder type. The usual custom is to remove the cylinder whenever any cleaning is done. Some of the oil passes unburnt through the valve, or valves, in the head of the cylinder, and as the lubricating oil is not used again in rotary-cylinder engines, the oil consumption of this type of engine is much greater than that of the stationary-cylinder type.

MISCELLANEOUS SUGGESTIONS

PROPELLER

94. Examining and Testing.—The propeller should be examined after long flights for any signs of loosening of the glue between the layers of wood, and for cracks, splinters, and other defects that might cause trouble. The bolts that fasten the propeller to the hub should be tightened frequently by removing the cotter pins and drawing up each nut a little at a time, until all are tight. One side should not be fully tightened at once, as this will throw the propeller out of line.

It is important that the propeller should track properly, and it should be tested by measuring from some fixed point on the fuselage to points on the ends of the propeller blades near the tips. The variation of this measurement must not be more than $\frac{1}{8}$ inch. If it is greater than this, the holding bolts should be loosened and one or more thicknesses of paper put between the wood and the fixed or inner flange of the hub, on the side needed to bring the propeller true.

95. The pitch, or angle, must also be alike on both ends of the propeller, and can be made so in the same way. The

angle can be tested by bringing the propeller to a horizontal position and measuring the angle near the widest part of the blade by use of a protractor and level and then giving the propeller a half turn, and measuring the other end in the same way. Care should be taken that the measurement is made at exactly the same distance from the center in both cases, and on both edges of the propeller, making four points equally distant from the center. The method of using the protractor is shown in Fig. 16. The level *a* rests on the edge of the propeller *b* and the protractor head *c* rests on the level. When the level is in a true horizontal position the protractor scale or blade *d*

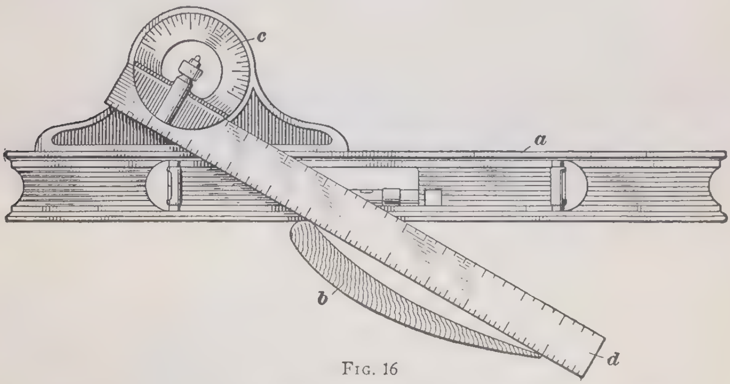


FIG. 16

is moved so as to touch the propeller at opposite edges, as shown in the illustration. The difference in pitch between the two blades must not be greater than $\frac{1}{16}$ inch.

96. After the propeller has been tested for tracking and pitch, all nuts must be tightened uniformly, and properly locked by cotter pins or locking wire. The fastening of the metal hub to the crank-craft should be examined occasionally to see that it is not working loose on the taper of the crank-shaft. This is done by removing the cotter or lock wire and testing to see whether there is any looseness in the retaining nuts. Care must be taken to replace the cotter securely.

97. Mounting.—When mounting a new propeller, it is important that it be located in the correct position. The

machine gun used on military planes is timed with the crank-shaft, and must of course fire through the revolving propeller. It is the custom to locate the key on the tapered end of the crank-shaft that drives the propeller hub, in relation to the timing of the machine gun. It is located so that the firing will be right when the key is in line with the axis of the propeller blades. Comparison with the old propeller will verify the position. The cranking of the engine by hand is made easier by this position of the propeller, as it is most favorable for "carrying over" the compression. The bolt holes in the propeller should be of a size that will give an easy driving fit of the bolts, and the tapered hole in the propeller must fit the hub so that there can be no possibility of lost motion. Nor should the bolts fit so tightly that there is danger of splitting the propeller as it is forced on the hub. No attempt should be made to remove the hub unless the crank-shaft, thrust bearing, or the hub itself, is found to be defective, and in case of renewal, the new hub must be lapped to fit the shaft.

98. Care of Propeller.—Propellers should always be given the very best of care, as so much depends on them, and they are so easily affected by outside influences. In case the aeroplane is to stand in the open for any length of time, the propeller should be protected from the sun and rain. Bags, or covers, made of heavy cloth, and generally provided for this purpose, are slipped over the blades and tied on by drawstrings.

STORING THE AEROPLANE

99. Engine.—When an aeroplane is to be put out of commission for some time, the gasoline should be drained out of the carbureter. If left in the float chamber, it will evaporate and leave a deposit that will very likely clog the gas passages when the engine is put in service again. All the water should be drained out of the cooling system and pains taken to see that there is none left in any of the pockets. Air pressure should be used, if necessary, to insure that all the water is driven out. The spark plugs should be removed, and old ones

substituted, or the holes closed up by screwing wooden plugs into them. The makers of some engines recommend that the valve mechanism be disassembled to such an extent as to allow all of the valves to close tightly. About once a week a little oil should be put into each cylinder, through the spark-plug openings, and the motor turned over a few times by hand, to prevent the formation of rust in the cylinders. The valve stems should be oiled with an oil can. It is a good plan to cover the engine with a heavy cloth to prevent dirt and dust from entering any of the movable parts.

100. Propeller.—The propeller should be removed, and hung on a peg that will reach all of the way through the shaft hole, and that is strong enough so that the upper surface of the peg will remain level. The propeller should be set in a vertical position to avoid warping or sagging, and should never be stored in a place that is either damp or very dry. The direct rays of the sun, especially, should be avoided, because excessive dryness as well as dampness affects the glue that holds the layers of wood together. It is bad practice to let propellers lean against a wall or hang horizontally, as stresses will be set up that will tend to throw them out of shape. If the propeller is not true throughout its length, it is very likely to vibrate badly, and vibration has a bad effect on the engine and its bearings.

101. Storage Battery.—There are two general methods of laying up a storage battery of the ordinary lead-plate type, known as the wet method and the dry method. In the wet method, the storage battery should be in a fully charged condition, and contain plenty of electrolyte at the time it is laid up. A freshening charge should then be given the battery about every 2 weeks, or at least once a month. It is a good plan to charge the battery for about 24 hours at one-half its usual charging rate, the low charging rate aiding in the removal of any undue sulphation. When a large number of storage batteries are kept in wet storage, they can be kept in good condition by continual charging at a very low rate, which method is known as a trickle charge. A 110-volt direct current

is to be used, which is suitable for as many as fifteen 3-cell batteries. The batteries are connected in series, and connected to the current source, placing a single 25-watt lamp in the line if not more than 10 batteries are charged, and a 40-watt lamp if more than 10 batteries are charged.

102. A storage battery can be kept in good condition for several months, or even years, by the dry method of storage. The battery should first be fully charged, that is, charged until the specific gravity shows no increase for a period of 5 or 6 hours. The electrolyte is then poured off, the groups separated, the separators removed, and the plates straightened out. To straighten the negative plates, a board equal in thickness to the thickness of the positive plate and two separators, is placed in each space between the negative plates in the group, and a board placed on each side of the group. The complete group assembly is then placed in a vise or regular plate press and tightened up slowly. After standing for a few minutes, the group is taken out of the press, the boards removed, and the group washed in clear water. When the groups have been treated in this way, they should be put in jars and covered with distilled water for 10 or 12 hours. They are then removed and dried, and if they begin to heat, should be repeatedly dipped into water until no further heating occurs. When the plates have dried thoroughly, they should lie immersed in clean, new electrolyte having a specific gravity of 1.275, and allowed to soak for 3 or 4 hours, using the battery jars for this purpose. They should then be rinsed and dried carefully and stored away.

103. In preparing the positive plates for storage, they should not be washed, but can be dipped in the acid used for the negative plates, to clean them. They should then be straightened in practically the same manner as the negative plates, but the pressure should not be very severe. They should be left in the vise or press for about 10 or 15 minutes, after which the edges may be trued up with flat-nosed pliers. Care must be taken not to crack the plates, and if any of them are cracked, or have buckled badly, they should be discarded,

and new ones substituted. The plates must not be allowed to stand in the light for any length of time. The jars with their covers should be washed out, the terminals cleaned, and a positive group placed in each jar. The negative groups are placed in a box with the covers and terminals, and the whole put in a case, labeled, and stored in a dark place. When the battery is to be put into commission again, acid of about 1.360 specific gravity should be put into the assembled battery, the battery fully charged and discharged, and the electrolyte adjusted to 1.280.

To prepare the special aviation battery for storage, the battery should be fully charged, the vent plugs removed, and the acid emptied. After the battery has stood upside down for about an hour to insure the thorough drainage of the electrolyte, it should be turned right side up, and the vent plugs replaced, after which it is ready for storage or export.

MANAGEMENT OF MARINE GAS ENGINES

INSTALLATION AND OPERATION

INSTALLING ENGINE AND AUXILIARIES

LOCATION OF PARTS

1. A common method of arranging the engine and accessory apparatus in a boat is indicated in the installation diagram shown in Fig. 1. While this is by no means the only arrangement, it will illustrate the relative location of the various parts. The parts shown in the diagram are: the shaft log *a,* stern post *b,* dead wood *c,* compression coupling *d,* sea cock *e,* muffler *f,* gasoline-supply tank *g,* engine exhaust pipe *h* leading from the engine to the muffler *f* and connected up by means of two unions *i,* and an elbow, a petcock *j* at lowest point in pipe, battery *k* and spark coil *l,* view (*b*), outboard gasoline-supply pipe *m,* view (*a*), from supply tank *g* to carbureter *n,* view (*b*), reverse rod *o* for forward, or bow, control, consisting of a galvanized-iron pipe with ends shaped for connection to reverse-gear mechanism and to lower end of reverse lever, which is held in the bracket *p,* regular reverse lever *q* in bow of boat, which can be removed from its usual position *q′* on gear-case *r,* air pipe *s* leading to whistle tank *t* to which the signal whistle is attached, brass strainer *u* on outlet pipe in gasoline tank, hand wheel *v* for operating valve in gasoline-supply pipe, and brass tank plate *w* provided with two small vent holes.

2. To install a marine gasoline engine so as to insure maximum safety and freedom from excessive vibration necessitates a thorough understanding of all the requirements to be met, including the construction and location of the fuel tanks, engine, carbureter, piping, etc., and also a thorough knowledge of the operation of the engine. Before any attempt is made to install the engine, there should be provided a working blueprint or drawing, indicating the distance from the center line of the crank-shaft of the engine to the under side of the bed or lugs, giving all the dimensions and showing plainly the outline of the base below the bearing side of the lugs. A drawing of the longitudinal and athwartship, or crosswise, pieces, with the dimensions plainly marked, should accompany the drawing of the engine base.

INSTALLING THE ENGINE

3. Location of Engine.—For light speed boats, the practice is to install the motor aft of the center of the boat that it may help lift the bow out of the water when running. This lifting, or *planing,* reduces the skin friction, which is one of the principal hindrances to speed. The location of the engine is a matter which is largely governed by the purpose for which the boat is intended. No hard-and-fast rule can be given. In general it should be placed so that its weight will not seriously affect the normal trim of the boat. Placing the motor in the center of the boat helps to give a long propeller shaft and consequently less pitch to the engine. It also makes a handy arrangement for the tanks. By placing a tank on either side, the fuel feed is equalized no matter how the boat may roll.

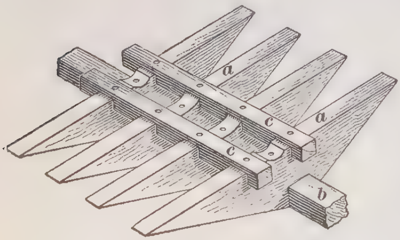


FIG. 2

4. One form of engine bed is shown in Fig. 2. First the cross-members *a,* which should be of sufficient size, are

fastened across the boat at about a distance of 12 inches from center to center. These pieces are fastened to the frames of the boat and lag-screwed or bolted to the keel *b*. They should be as wide from side to side as circumstances will permit and if possible should extend to the round of the bilge. The fore-and-aft timbers *c* are notched and lag-screwed or bolted to the athwartship pieces *a* as shown. If bolted, the fitting must be done before the crosspieces are laid.

5. Lining Up the Shaft.—When laying the engine bed, the first thing to do is to line up for the shaft. With the engine will usually be given the height the center of the flywheel should be placed above the bottom of the boat. If no height has been given, the distance from the center to the rim of the flywheel should be measured and 3 or 4 inches added for clearance from the bottom of the boat. An upright should be nailed to the bottom at the point where the face of the flywheel will come; this should be cut off at the height of the center of the wheel. The object of the clearance is to prevent the wheel, when revolving, from throwing about bilge water that may be in the bottom of the boat. The objection to too much clearance is that it is liable to give the engine too great a pitch. The engine should be as nearly level as possible, and in any case the pitch must not exceed 3 inches to the foot.

6. After the upright has been cut off, a nail should be driven into it in the exact center of the width of the boat. A string should next be passed through the hole in the shaft log and a stick tied to its outside end. The string should be pulled taut and its inside end fastened to the nail, close down; the stick drawn flat against the hole on the outside is then shifted until the string passes through the exact center of the hole. The top of the engine bed should be from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch lower than the engine is to be placed, and must run parallel to the string that passes through the shaft-log hole. The distance between the top of the bed and the string should be made equal to the distance between the under side of the engine and the center of the shaft plus $\frac{3}{8}$ inch.

7. Placing Engine on Its Bed.—The engine is next placed on the bed and the shaft run through the shaft-log boring and propped in position. The engine is then lined up with the shaft and wedges placed under the four corners to force it into position. The wedges should be of hard wood, about 6 inches or 10 inches long and tapered from $\frac{3}{4}$ inch to nothing. After the engine has been bolted to the bed, the shaft may be slipped in place and fastened. When nails or bolts are to be driven through the wedges, holes should be bored to prevent their splitting.

When placing the stuffingbox on the dead wood, care should be taken that it lies at perfect right angles with the shaft. If it does not, the dead wood must be cut into until the stuffingbox is at right angles with the shaft, or else, when the box nut is screwed home it will bind on the shaft. To know if all is well here the engine should be turned by hand with the petcocks open. With cylinders and bearings well oiled, the engine should now crank easily.

8. Propeller.—The propeller should be placed as close to the stern of the boat as is safe. By this is meant that enough clearance must be provided so that a bent blade will not hit and cut the stern. When a blade is slightly bent, it can be hammered back into place by laying it on a block of wood and having another piece of wood between the blade and the hammer. If much bent it should be sent to the maker, who will put it back into form. A blade that has been badly bent is liable to break off at any time when in use. The top of blades should be submerged 2 or more inches under the surface.

If the propeller turns in the direction of the hands of a clock when standing back of the stern and looking at it, the twist of the wheel in the water will tend to push the stern of the boat to the right, or starboard. If the propeller turns in the opposite direction, the push of the stern will be the opposite. The reason for this is that the water below is more solid than that at the surface, and offers greater resistance to the thrust of the blade. Because of this a boat turns in a smaller circle one way than the other.

Propellers will sometimes jar loose. They should be keyed on and a setscrew used, or a cotter pin placed through the end of the shaft.

9. Salt-Water Fittings.—Special fittings are required for use in salt water because bronze or brass near iron or steel in salt water sets up a galvanic action that will quickly eat away the iron. If a bronze propeller is placed on an iron shaft, this action will quickly eat away the shaft and cause the propeller to be lost. Iron pipes for the water circulation will soon choke with rust and will fill the passages in the water-jacket with rust. The bolts through the ground-joint pipes in the water circulation on either side of the water-jackets should be of brass or bronze. Iron bolts will readily corrode. There should be no iron or steel struts near any bronze or brass fittings. Stuffingbox and bolts should be of bronze, and also the shaft log if it is made of metal. There should be nothing whatever in the water circulation that is made of anything but brass or bronze. The interior of the water-jacket and the exterior of the cylinders are of such large construction that the corroding action is slow within them, but they should be cleaned out once a year.

FUEL TANKS

10. Shape of Tank.—For the storage of the gasoline, kerosene, or crude fuel oil, the tank required should be so constructed that it will retain the fuel under all weather conditions. For economy of space, tanks are usually made to fit into the bow, the bilge (side), or the stern of the boat. These tanks present large flat surfaces at their different sides, against which the 10 to 40 gallons of fuel that they contain deals heavy blows when the boat is in a seaway. In order to prevent the fuel from rushing from end to end of the tank and also to support, or stay, the sides and bottoms, transverse partitions, or **baffle plates,** are provided in the interior of the tanks. These should be open at the bottom to allow a free passage of the contents from one compartment to another. By

the use of these plates, the force with which the fuel strikes the sides and ends of the tank is greatly reduced.

11. A tank made in cylindrical form is superior to any other on account of its greater strength and the absence of flat surfaces to be pounded. The curves of the walls turn all rushes of liquid into glancing blows. However, it is better that even this style of tank be fitted with baffle plates, both as a matter of reducing strains and of stilling the noise of the swashing that goes on in undivided tanks during a seaway.

Flat-sided tanks should have boards flattened up against them and braced to help relieve the strain, or pressure, from the inside. They should also have a raised rim around the outside of the top edges, with a small pipe leading overboard to discharge gasoline from a spill or overflow. The superiority of the seamless cylindrical tank is demonstrated if the air-pressure feed-system is used, it being a difficult matter to keep the joints of a flat-sided tank air-tight on account of the surging of the fuel against them.

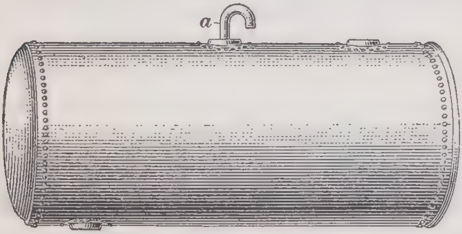


Fig. 3

12. **Tank Vents.**—A vent is necessary in a tank to admit air to supply the space vacated by the fuel that has flowed to the motor; otherwise, a vacuum would be created and the flow of fuel through the pipes be suspended. The vent should be placed so that it will not admit dirt or water. Perhaps the best method of venting is by means of a curved pipe opening into the top of the tank, as shown at *a*, Fig. 3. Air, but no dirt, can enter this pipe. Another good way is to force a hole through the screw thread just below the lower edge of the filling cap. Still another method is to pierce the top center of the filling cap with a very fine hole. In this case it is better during rain, fog, or spray, to cover the cap with anything handy. The hole must be only the size of a pin.

13. Materials Used.—Copper is the most common metal used in making tanks because it is not corroded by gasoline or oils. Steel tanks are also often used but these should be tin-lined, otherwise the action of the water at times found in gasoline will cause the interior to rust and deposit a sediment in the fuel that will be conveyed to the pipes and carbureter.

14. Cleaning the Tanks.—All tanks should have a draw-off cock placed at the lowest point of drainage for the purpose of getting rid of the sediment that is sure to find its way into them. When it is suspected that the tank has any foreign matter in it, the valve in the pipe line should be shut off and a receptacle placed under the drainage cock. The fuel should then be let off from the tank as quickly as possible, so that it will carry with it any dirt that may be inside. Gasoline poured through the tank will clean it still further. The fuel thus flushed out of the tank can be strained through a chamois skin and regular strainer, and then poured back into the tank.

15. Position of Tanks.—The ideal position for tanks is to have one on each side of the boat with a pipe leading from each to a main supply pipe for the carbureter. In this position, no matter how the boat is rolling, the supply to the carbureter remains constant. The bottom of the tanks should be at least 6 inches above the level of the float in the carbureter to insure a flow of gasoline to the engine. With a 6-inch elevation, the tank may be placed in any part of the boat with the assurance that even in a seaway there will be no serious results. The motor may run fitfully in a bad sea, but with either vaporizer or carbureter it will keep going if it is otherwise in good condition.

16. Care of Tanks.—All gasoline tanks should be painted on account of the corrosive action of salt water. While it is the common impression that copper will not corrode, it has been found that, if unrestrained, salt water will eat through $\frac{1}{16}$ inch of copper in two seasons.

If a leak develops, it can be plugged with common brown soap and painted with a thin coat of shellac. After this is dry, a second coat of shellac should be applied and then a piece of any kind of thin cloth that has been wet with shellac should be spread over the leak. This will make a very satisfactory temporary repair.

17. Air Pressure.—Sometimes it is necessary to place the gasoline tanks low down. This steadies the boat when properly placed, but it also necessitates a method of raising the fuel to the carbureter. The gasoline is usually forced to the carbureter by means of air pressure derived from a hand pump. The pump is connected to the tank by a pipe and the gasoline is thus kept under the necessary pressure. The tank and pipes in this system must of course be perfectly air-tight. Joints can be made air-tight by the use of hot sealing wax, and small leaks in the top of the tank may be taken care of by using shellac.

If air pressure is used, a small auxiliary gravity tank situated near the motor is almost a necessity. With it one is in a measure independent of the air pressure, should it fail either by the air pipe becoming obstructed or because of leaks. In case of such an accident, the auxiliary tank can be kept supplied by drawing from the main tank by siphoning, or by inserting a small pump into the tank, or dipping from it through the cap opening.

18. Tank Indicators.—In any tank, the outlet pipe should be placed about $\frac{1}{2}$ inch above the bottom of the tank so that sediment will not flow into it. The amount of gasoline that a tank contains at any time may be ascertained by means of a measuring stick, which can easily be made for any tank. When making such a stick, fuel should first be poured into the tank until it begins to run out of the cock in the pipe line; it should then be poured in 1 gallon at a time. After pouring in each gallon, a smooth stick should be inserted to the bottom of the tank and notched where the level of each gallon of fuel comes. This stick can then be used for finding the quantity of fuel in the tank at any subsequent time. Many of the

cylindrical tanks are supplied with indicators that automatically tell the quantity within. Gauges for this purpose are also made. They should not be placed in the pipe line for the reason that if anything happened to the gauge the supply of fuel would be cut off.

19. A gasoline tank depth gauge, or indicator, for showing the depth of gasoline in the supply tank, is illustrated in Fig. 4. A float *a* rests on the top of the gasoline and rises and falls with it. A slot in the center of the float engages with a twisted flat stem *b*. As the float rises, this stem is moved around and carries with it a hand, or pointer, *c*, which moves over a dial graduated to indicate the quantity of gasoline in the tank. Rotary motion of the float *a* is prevented by the frame *d*, with which lugs at the edge of the float engage.

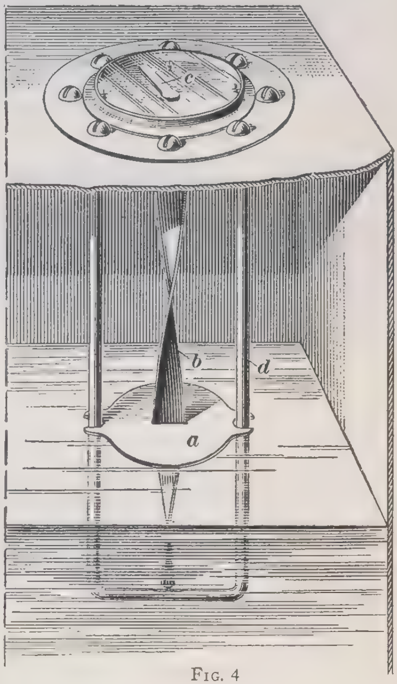


Fig. 4

20. Filling a Tank. To fill a tank with fuel, a strainer funnel provided with a fine wire mesh or an ordinary funnel with a piece of chamois skin spread over it should be used. Before removing the cap from the tank, the dust should be brushed or blown from it. The cap should be laid down bottom up, so that it will not pick up dust on its edges and thus get dirt into the fuel. If the tank is new, it should be flushed thoroughly before being filled.

The capacity of a tank should be enough to run the engine at least 20 hours. The supply can be figured for any engine

from the fact that a two-cycle engine generally uses about $1\frac{1}{4}$ pints of gasoline per hour per horsepower, and a four-cycle engine, about $1\frac{1}{8}$ pints per hour per horsepower.

GASOLINE PIPE LINE

21. The pipe line should leave the tank with a spiral of two or more coils twisted into it for the purpose of taking up vibration from the motor and shocks from the waves. Coils should also be twisted into the pipe line wherever it is joined to any part that is fastened to anything stationary, the reason being that every boat buckles or vibrates more or less in a seaway and unless the pipe can give and take, it is liable to be snapped. When pipe lines are not fitted in this way, it is necessary to carry an extra length of pipe with nipples fitted on the ends for use in case of accident. If other tanks are in use the pipes from them should be brought to the main line pipe.

22. Fuel Strainers.—A fuel strainer should be set in the main pipe line for the purpose of catching any dirt or water that may be in the gasoline. The strainer should be opened frequently, say, every eight or ten runs, to clean the fine-wire mesh. Sometimes, when oil is mixed with the gasoline in the tank, the fine mesh of the strainer gathers a gum-like substance that in time clogs enough to stop the flow of fuel. The catch of water may easily be run off by a turn of the cock at the bottom of the strainer. Frequent cleaning of the strainer will prevent the corroding of its screens. With all precaution and care the strainer will occasionally become damaged; when it does a short piece of pipe should be inserted in the place occupied by the strainer. If the gasoline is properly strained before being poured into the tank, the probability is that the flow will continue for many trips without trouble.

23. Placing the Pipe Line.—The pipe line should not be laid where it can be trodden upon, as it may be flattened, or broken, for the finely drawn pipe is fairly brittle. If necessary to bring it across the floor it should be run in a corner or

covered the same as electric wires are covered when on the outside of walls. Leaks in the line can easily be treated with shellac, the best shellac being that which has coagulated a little in the bottom of a bottle or box.

The pipe line should be of copper, and should not be run under floors, or in out-of-the-way or inaccessible places. It should be renewed every 2 or 3 years, because it crystallizes under the constant vibration. It also may corrode in spots under the action of salt water. If it clogs, the fuel should be shut off and the pipe disconnected. It can then be blown out with an air pump, or a long wire can be run through it. It is well to have all pipes as short as possible. Ground joints in the line are more easily handled than threaded ones. Ground joints are smooth-ended and are drawn together by the use of box-like nuts.

A rubber section should never be installed in the gasoline pipe line, because gasoline is a solvent for rubber and the rubber will be carried into the piston and rings. The gasoline supply pipe should be of good size so that it will not become obstructed easily.

LOCATION OF CONTROL LEVERS

24. Control Levers on Engine.—In many boats, especially the smaller and less expensive ones, the levers for controlling the time of ignition and the throttle valve are located on some part of the engine, within easy reach of the operator. The direction in which to move the spark lever to alter the ignition timing or the throttle lever to alter the position of the throttle valve is given in the instruction book sent out by the maker of the engine. When one does not know the direction in which to move them, and the instructions of the maker are not at hand, this information may sometimes be obtained by inspection. For instance, in order to advance the spark, it is necessary to rotate the movable part of the timer in a direction opposite to that from which the timer rotor is turning. In like manner, the spark is retarded, or made to occur later, by moving the lever in the same direction

in which the rotor turns. These directions apply to timers, but in the case of magneto ignition, where the spark time is varied by moving some part of the magneto interrupter, it is more difficult to determine the direction in which to rotate the lever. One should not attempt to start an engine until he is sure that the spark is retarded; otherwise, serious injury may result.

In some makes of carbureters it is possible to tell by inspection when the throttle valve is open and when it is closed.

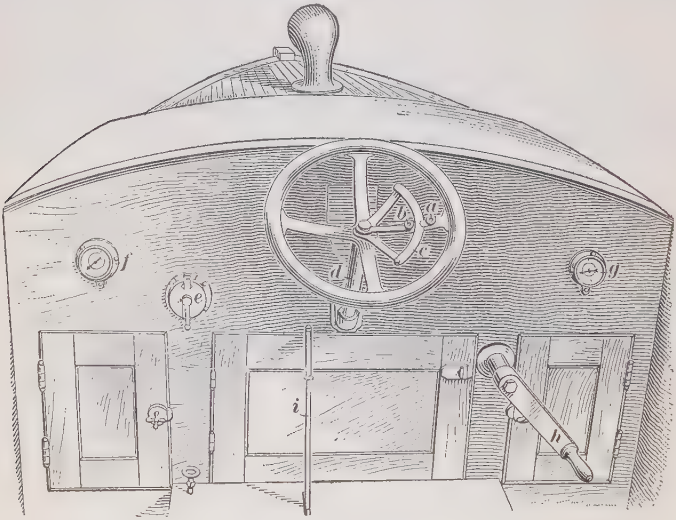


Fig. 5

However, by attempting to start the engine with the throttle lever in different positions, the open and closed positions may be ascertained.

It is always the best plan, especially for the novice, to follow the maker's instructions or get the information from some properly informed person in the vicinity and thus clear away any doubt as to how to obtain the desired results.

25. Bulkhead Control.—In a large number of boats, the throttle valve and timer are operated from levers located on the bulkhead, forming the **bulkhead control.** This form of control is made possible in the modern boat with its

engine well forwards and the bulkhead between the motor and the helmsman. The switches and push buttons are fastened on the bulkhead within easy reach of the operator and are wired to the battery or magneto, or to both where a double or dual system of ignition is found. The levers are sometimes fastened to the bulkhead in the place most convenient to the steering wheel and a system of rods and levers lead to the timer or magneto and to the carbureter, or they may be located on top the steering wheel. With the latter arrangement, the control rods are brought up through the hollow steering-wheel shaft. Sometimes the levers are located under the steering wheel.

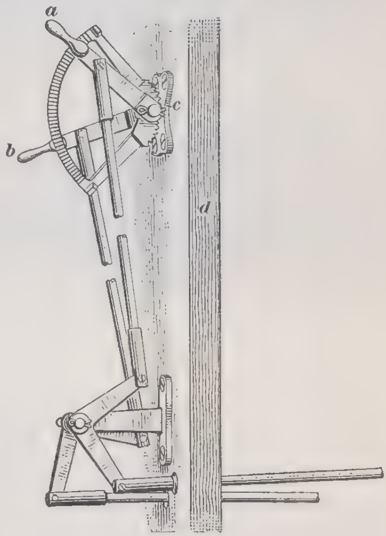


Fig. 6

26. In Fig. 5 is shown a bulkhead control arrangement in which the control levers are located on the steering wheel. The throttle lever *a* and the spark lever *b* are arranged on a quadrant *c*, around which they may be moved. They are connected to the timing device and the carbureter by means of rods passing down through the shaft *d* of the steering wheel. The switch *e* and gauges *f* and *g* are located on the bulkhead within easy reach of the steering wheel. A starting crank for the purpose of turning the engine over by hand when starting, is located at *h*, and the reversing-gear lever at *i*. This is a very convenient arrangement and one that is coming more and more into use. The bulkhead control is also sometimes employed where the engine is located aft of the cockpit, in which case the levers and rods must run aft of the steering wheel instead of forward.

27. In some cases of bulkhead control the spark and throttle levers are arranged so that they must be moved up or down in order to operate the throttle valve or the timer. Such an arrangement is shown in Fig. 6. The levers *a* and *b* are carried on the bracket *c* and are connected to the throttle valve and timer by means of the rods and bell-cranks as shown. In this construction, the rods pass from the bell-cranks, through the bulkhead *d*, directly to the devices they are meant to operate.

Another system of levers and rods is shown in Fig. 7, where the rod *a* from the lever *b* passes through the bulkhead to a bell-crank *c*. From this bell-crank a second rod *d* passes to

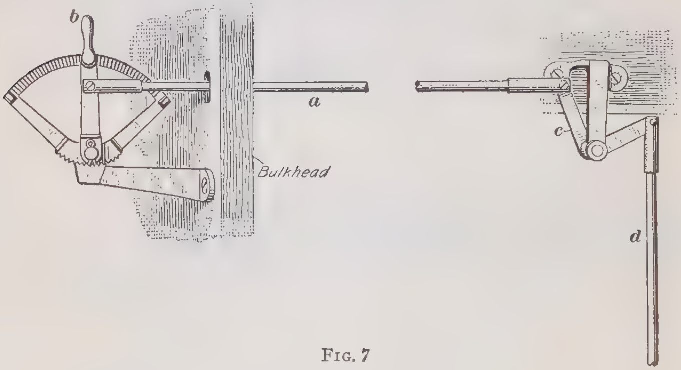


Fig. 7

the throttle valve or timer. In both Figs. 6 and 7 the control levers are located directly on the bulkhead and not on the steering wheel.

28. When installing the rods for a bulkhead control, the greatest care must be exercised to see that there is but little lost motion. Some lost motion cannot be helped but it must be small. Rods for the purpose of connecting the levers to the different parts, to be satisfactory, should be fitted with ball-jointed adjustable ends. With this type of rod the length can be regulated to a nicety.

When attaching the rods to the spark, be sure at the time of connecting that the spark is half way between full advance and full retard. In like manner the throttle should be connected when it is half way between full open and full shut.

CIRCULATING PUMPS

29. Plunger Pump.—A type of water-circulating pump used extensively on marine engines, and especially on the smaller sizes, is the plunger pump, one form of which is shown in section in Fig. 8. In this pump, the water is forced through the cooling system by means of the hollow piston or plunger *a*, which is driven backwards and forwards in the barrel *b* by means of the eccentric *c* surrounding the crank-shaft *d*. Check-valves *e* and *f* prevent the water from flowing back into the inlet pipe *g*. As the plunger moves forwards toward the crank-shaft, the suction thereby created lifts the check-valve *e* from its seat and draws water into the barrel. On its return

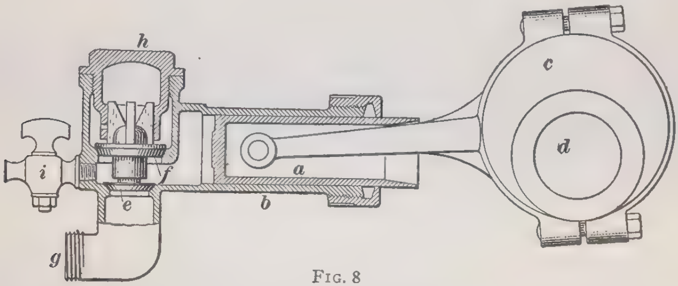


Fig. 8

stroke, the plunger forces the water through the check-valve *f* into the passage that leads to the cylinder jacket.

During the backward stroke of the plunger the check-valve *e* prevents the water from escaping back into the pipe *g*; and during the forward stroke, the valve *f* prevents the water from being drawn from the jacket space back into the pump. The check-valves may be taken out by removing the plug *h*. The cock *i* is for the purpose of draining the water from the pump barrel.

30. A form of single-acting pump used on an oil engine for the circulation of cooling water as well as lubricating oil is shown in section in Fig. 9. The body *a* of the pump is bolted to a supporting bracket *b* by the three bolts *c*. The plunger *d* is given a reciprocating motion through the link *e*, which is connected to an eccentric strap working on an

eccentric on the engine shaft. The valve *f* is the suction valve and the valve *g* the discharge valve. When the pump

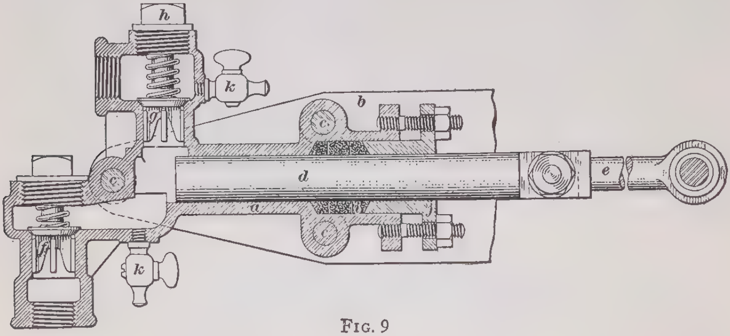


FIG. 9

is to be started for the first time, or after a long shutdown, it will need to be primed. To do this it is necessary to remove the plug *h*, lift the discharge valve, and fill the pump and piping with water. Hemp packing or candle wick saturated with oil is used to pack the plunger at *i*, being compressed by the gland *j*. The petcocks *k* are used to test the action of the pump. If water is emitted in pulsations when these cocks are opened, the pump is operating properly.

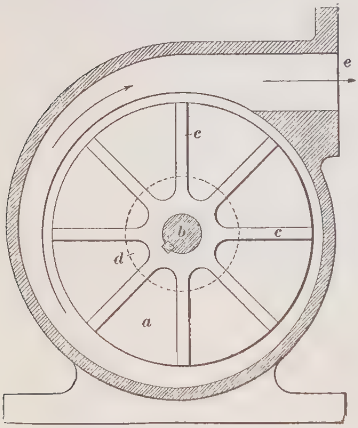


FIG. 10

31. Centrifugal Pump. Another type of water-circulating pump used quite extensively is the centrifugal pump, which operates on the principle shown in Fig. 10. In this pump the only moving part is a bronze or aluminum disk *a*, keyed on a shaft *b*, and on one face are cast blades *c*, which may be radial, as shown, or bent backwards. The shaft carries the disk *a* at one end, and works through a stuffingbox to prevent leakage. The water enters the pump through an opening indi-

cated by the dotted circle *d*. This inlet is on the side of the pump toward the observer, and, therefore, cannot be seen in the illustration. As the water enters the pump, it meets the blades *c* and is carried around and thrown outwards by centrifugal force, being expelled at *e*, provided the passage outside the pump is open.

32. It is not necessary that either the disk or the blades have a water-tight fit in the casing, because the pump simply establishes a difference in pressure between the points *d* and *e*, Fig. 10, but does not positively force the water. Consequently, if the flow is obstructed for any reason, the pump can still be revolved without injury to itself. Moreover, this type of pump does not lose its efficiency through wear. The pump is run at quite a high speed, generally about twice the speed of the engine; and if the resistance to circulation is not too great, it will throw quite a large stream of water. It is usually mounted on the crank-case of the engine and geared to the cam-shaft or to the two-to-one pinion.

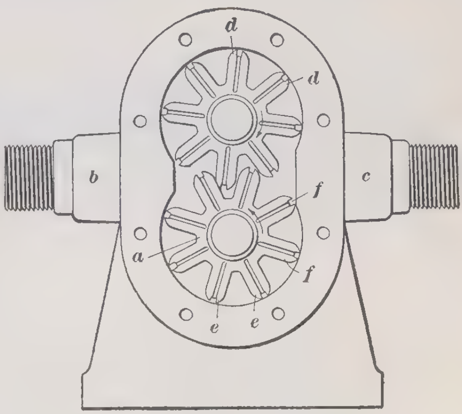


FIG. 11

33. Gear-Pump.—A type of pump used to some extent for circulating purposes is the gear-pump shown in Fig. 11. It operates equally well in either direction. One of the two gear-shaped pump members *a* is driven by a shaft and rotates the other with it. If the direction of rotation is that shown by the arrows, the water will enter at *b*, and pass out at *c*, being carried around by the outer teeth *d* and *e* and expelled as the teeth come together. The particular pump shown has

grooves f in the sides and tips of the teeth, which, it is claimed, prevent to a large extent leakage past the teeth, and thereby increase considerably the efficiency of the pump.

EXHAUST CONNECTIONS

34. Exhaust Pipe.—The larger an exhaust pipe is, the better the engine will work and the more power it will develop. There should be but few bends in it and these should be at as large an angle as possible. Every 45° elbow gives a resistance equal to the friction of 15 feet of pipe. The passage of water through the exhaust pipe reduces the speed of the boat somewhat, but it is necessary for the purpose of keeping the pipe cool. The exhaust should not pass near a fuel tank even though the pipe is covered with asbestos. Accidents to the covering of the pipe may occur and consequently there is danger of fire or an explosion.

35. Underwater Exhausts.—Marine engines are cooled by the circulation of water through the water-jacket

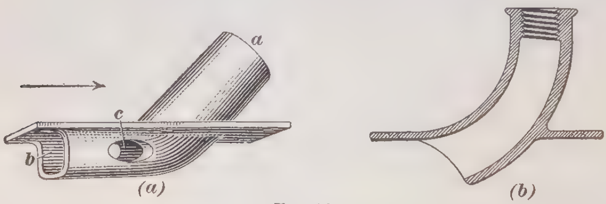


FIG. 12

of the engine cylinder. A pump attached to the engine draws water through the bottom of the boat, sends it to the engine, and finally discharges it overboard, usually by way of the exhaust pipe, which is sometimes led under water, discharging through a special fitting, one form of which is shown in Fig. 12 (a).

The exhaust enters the fitting at a and leaves at b, under the water, the boat moving in the direction of the arrow. On account of the velocity of the boat, water rushes into the openings c, into the exhaust pipe, and out with the exhaust at b. This arrangement tends to increase the velocity of the

exhaust and reduce the back pressure on the engine. Another form of exhaust nozzle is shown in section in (*b*). This form resembles that shown in (*a*), except that the passage *c* is omitted. Such devices are known as *underwater exhausts*, or *submerged exhausts*. Their purpose is to reduce the noise of the exhaust and to carry the gases under water, where their odor will not be objectionable.

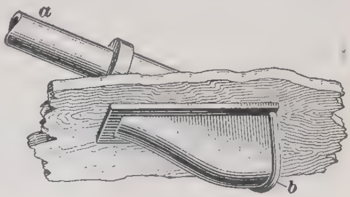


Fig. 13

36. Another type of underwater exhaust is shown fitted to the side planking in Fig. 13. The exhaust gases from the engine enter through the pipe *a* and escape into the water by way of the outlet *b*. The suction of the water as the boat moves ahead serves to draw the gases out and to relieve any back pressure. In Fig. 14 (*a*) is shown

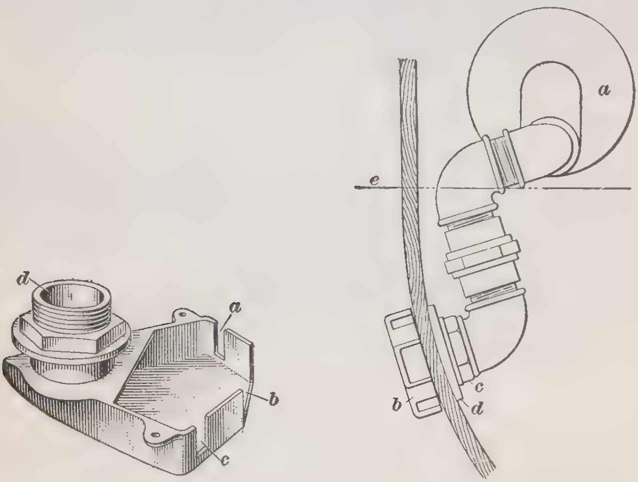


Fig. 14

an underwater exhaust containing three outlets, *a*, *b*, and *c*. The gases enter through the inlet *d* and are deflected toward the outlets and allowed to escape into the water. This device is shown installed in a boat, together with an expansion cham-

ber, in (*b*). The expansion chamber *a* is simply a cylinder into which the exhaust gases from the engine are led and allowed to expand before entering the exhaust header *b*. The header, or underwater exhaust, is held in place to the outside of the side planking by the locknut *c*. Rubber packing is placed in the header against the outside of the boat and a wooden washer *d* is placed on the inside of the planking under the locknut, in order to prevent water from leaking into the boat around the threads under the nut. The water-line is shown at *e*.

The expansion chamber *a* and exhaust header *b* are connected up by means of elbows and a union, so as to form a sort of universal joint that will prevent the pipe from breaking in case of vibration of the boat. It is essential that some provision of this kind be made in piping connections on a boat, because the distance between any two separate parts so connected does not remain exactly the same, but varies on account of the vibration caused by the movement of the boat.

37. In using the underwater exhaust, it is customary to have the exhaust make its exit at some point just on the water-line. Then, when the boat is under way and begins to gather speed the stern will settle and submerge the exit. Directly at the stern center is not a good position on account of the dragged water flowing directly against the stern instead of away from it. This dead water, as it is called, may be detected by dropping a piece of cotton waste on the surface of the water an inch or two from the stern and observing its action. A better place for the exhaust is on the side of the stern where a strong current is sure to carry the exhaust away instead of pushing it back.

38. With the exhaust under water at all times it is often hard, if not impossible, to start the motor because of the resulting back pressure. On many boats using the underwater system of muffling it can be readily demonstrated by having some people stand near the exit of a water-level exhaust, that the sinking of the exhaust several inches below the surface will materially slow down, if it does not entirely stop, the engine.

The exhaust pipe is sometimes installed at an upward angle from the muffler to the point of exit. This renders the muffler liable to become partly filled with water when a sea rises well above the opening. It is better practice to carry the pipe in an arch, or even at a slight angle, downwards to the point of exit and thus prevent the inflow of water.

39. Mufflers.—A **muffler,** or **silencer,** is a device used for deadening the noise of the exhaust gases as they escape into the atmosphere at the end of the working stroke of a gasoline engine. The sound is deadened, or muffled, by leading the gases into a chamber where they are cooled somewhat and allowed to expand so that the pressure at which they enter the air will be reduced. Mufflers constructed for marine

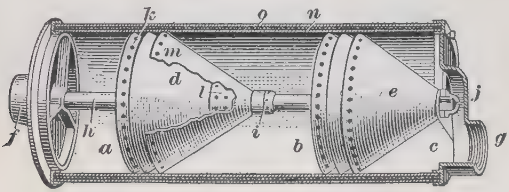


FIG. 15

engines are known as wet and jacketed mufflers; or, the construction may represent a combination of both of these types.

In the *jacketed muffler,* water from the cylinder water-jacket outlet is allowed to circulate around the outside of the muffler, to assist in cooling the gases and thereby reducing their volume. The *wet muffler* is one in which all or a part of the exhaust water from the water-jacket is discharged into the engine exhaust, where it is turned into steam, cools the exhaust gases, and combines with them, increasing their density and sluggishness, and thereby muffling the exhaust. The water from a jacketed muffler may be diverted into the exhaust itself, to further reduce the sound of the exhaust, this being the combination system already mentioned. The wet and combination mufflers are the most common types used in marine service.

40. A typical marine engine muffler is illustrated in Fig. 15, which is a sectional view showing the interior arrangement.

This muffler comprises three expansion chambers *a*, *b*, and *c*, separated by two sets of conical baffle plates *d* and *e*. The exhaust gases and waste water from the cooling system enter the muffler by the inlet opening *f* and pass out through the outlet *g*, which is placed low in the outlet head to provide a means of escape for any surplus water that may accumulate. A part of the gases entering the muffler passes directly into the chamber *a*, while the remainder passes through the axial tube *h*, some escaping by means of the holes *i* into the middle chamber *b* and some going clear through the tube and out of the nozzle *j*.

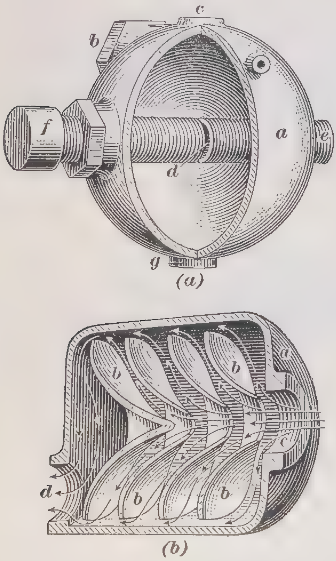


Fig. 16

41. The cones that separate the expansion chambers are perforated at top and bottom, so that the gases that enter the chamber *a*, Fig. 15, pass through the holes *k* in the first cone, *l* in the second cone, and *m* in the last, into the chamber *b*. The gas passing out of the nozzle *j* at high velocity creates a vacuum in the chamber *c*, so that the gases move rapidly into it from the second chamber *b* by way of the holes in the conical baffle plates *e*. This rapid forward movement of the exhaust gases through the first and second chambers to the third, causes a sudden expansion, removing the heat from the gas and reducing the pressure in the muffler, so that the gases escape into the atmosphere without any noise.

The walls of the muffler consist of an inner layer *n* of heavy material and an outer metal covering *o*, separated by a layer of asbestos, so as to prevent metallic sound from the gas impinging against the walls. To secure best results the asbestos used should be wire-woven.

This muffler is designed for use where the water is run into the exhaust pipe near the engine. Some mufflers are made with a separate water inlet located in the same end that the gas inlet opens into.

42. Two types of marine engine mufflers in which the water mixes with the exhaust gases are shown in Fig. 16. In view (*a*) is shown a silencer consisting of a spherical shell *a*, into which the exhaust gas passes by way of the inlet *b* and the water by way of the opening *c*. The gases expand in the shell, and become cooled by contact with the water, after which they enter the exhaust outlet at *d* and pass out at the opening *e*. The opening for the exhaust outlet in the center of the chamber is adjustable by screwing in or out the long nipple *f*. The larger portion of the water passes out of the drain *g*, a small portion being taken out with the exhaust gas. The location of the exhaust inlet with the water inlet directly in the path of the entering gases gives the water and gases a circular motion, allowing the gas to cool and expand and reducing the pressure.

43. In Fig. 16 (*b*) is shown a muffler that consists of the cylinder *a* fitted with deflecting plates *b*. The exhaust gases and circulating water enter the cylinder at *c* and escape by way of the opening *d*. Part of the exhaust gases passes through the holes in the center of the baffle plates and part passes between the edges of the plates and the wall of the muffler, as shown by the arrows. The deflecting plates break up the force of the incoming gases and allow them to expand, thus reducing the pressure and allowing the exhaust to pass into the atmosphere without noise.

44. When a muffler is used, the power of the engine is reduced to a slight extent due to the back pressure produced by the additional friction of the muffler. On account of this, it is a good plan to have the engine fitted with a muffler cut-out, or two-way exhaust, by means of which the engine may exhaust into the open air when occasion permits. The boat may be started more readily by this means and when running in localities where the laws permit it, the muffler may be cut out and the maximum power obtained without increasing the wear

on the engine. An increase of power is obtained in speed boats by doing away with the manifold, or common exhaust pipe, and having a separate pipe for each cylinder. Where facilities are at hand to make the change, additional power can sometimes be obtained by leading the exhaust from each cylinder to one common pipe of larger dimensions, the opening to which is aft of the last cylinder.

REVERSING GEARS

45. In the handling of motor boats, it is often desirable to back the engine or turn the propeller in a direction opposite to that for going ahead, even when there is only one set of

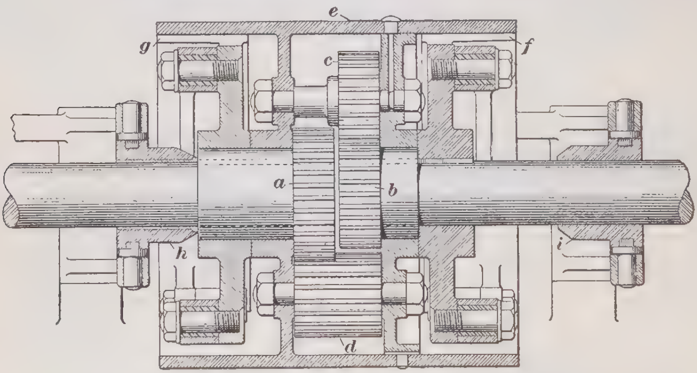


Fig. 17

gears for forward speed, and hence no speed-change device. In such cases, it is desirable to have a device by means of which the direction of motion of the propeller shaft may be reversed while the engine runs continuously in the one direction, which is usually the case with four-cycle engines. The reverse motion of the propeller is sometimes needed to check the speed of the boat, to bring it to rest, or to run the boat astern.

There are several forms of reversing mechanisms, but they are similar in principle so far as the motion of the engine and propeller shaft is concerned, differing only in the method of making the connections for the reversal of motion. In some

cases, spur gears and clutches are used; in others, spur gears and sliding feathers; and in still others, bevel gears.

46. In Fig. 17 is shown a reversing gear that depends on friction clutches for its operation. The propeller shaft is divided into two parts, the one, connected to the propeller, carrying the gear *a*, and the other, connected to the engine, carrying the gear *b*. The gears *c* and *d* mesh with these gears. The gear *b* is slightly smaller than gear *a*, and *c* meshes with *b*, and *d* with *a*. Another gear similar to *c*, but not shown, meshes with *d* and *b*, while one similar to *d* meshes with *a* and *c*. The gears *c* and *d* run on pins that are held in place in the web of the drum *e*. There are two friction clutches *f* and *g*, the latter serving to hold the drum *e* stationary when the movement of the propeller shaft is to be reversed. To reverse the motion of the propeller shaft while the engine is running, the spreader *h* is thrown inwards by the reverse lever, so that the clutch *g*, which is stationary, grips the drum *e* and holds it. The pins on which the gears *c* and *d* revolve are thus also held stationary, and the relative motions of the gears are as shown diagrammatically in Fig. 18. The crank-shaft transmits motion to the gear *b*, in the direction indicated by the arrow. The gear *c* in mesh with *b* turns in the opposite direction and transmits motion through a long gear *c′*, not shown in Fig. 17, to the gear *a* on the propeller shaft, which is thus made to move in a direction opposite to that of the gear *b* on the end of the driving shaft. The gear *b* is also in mesh with the gear *d′*, which turns gear *d* in the same direction as that in which the gear *c′* moves, and hence helps to turn gear *a* in a direction opposite to that in which the driving gear *b* moves. The gears *d′* and *d* are duplicates of the gears *c* and *c′*, each pair transmitting a portion of the power when the lever is reversed. When the reverse spreader *h* is thrown out of engagement and the forward spreader *i* is thrown in, the same movement of the reverse lever serving to accomplish both

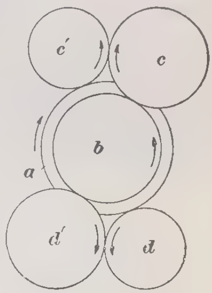


Fig. 18

operations, the clutch *f* grips the drum *e*, which is thereby caused to rotate with the driving shaft to which the clutch *f* is keyed, all the gears being locked together. The gears therefore have no relative motion, and the whole mechanism, including the propeller shaft, rotates at the speed of the driving shaft.

47. In Fig. 19 is shown another form of reversing gear. The internal construction consists of a gear keyed to the crank-shaft of the engine, surrounded by four or more pinion gears *a* running on stubs *b*, supported at one end by the cover *c*, which

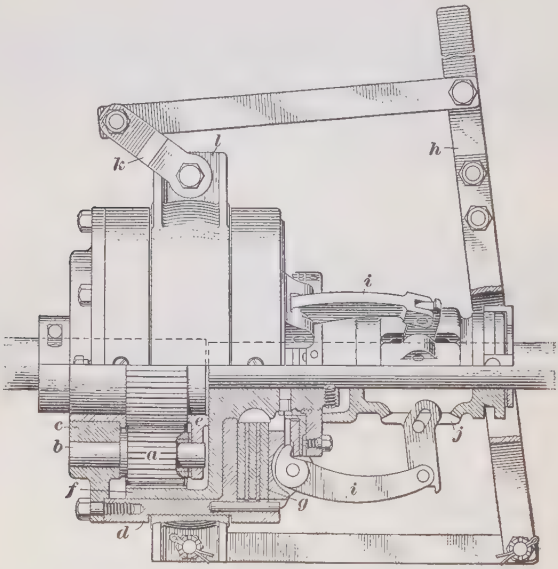


Fig. 19

is bolted to the external case *d*, and at the other end by a bronze pinion support *e*. The pinion gears *a* in turn mesh with the propeller gear *f*, which is an internal gear.

The forward drive is obtained by a multiple-disk clutch, the surfaces of which are formed by the rear end of the propeller gear *f*, a partition or web in the case *d*, and thin plates *g*, one half of which are keyed to the case *d* and the other half to the propeller gear. When the lever *h* is thrown forwards, the fingers *i* are expanded by a togglejoint *j* so that the friction

surfaces are clamped together, causing the propeller gear *f* and the case *d* to revolve as one piece. As the cover *c* is bolted to the case *d* and turns with it, the pinion gears *a* that are supported by the studs *b* in the cover and are in mesh with the propeller gear cannot revolve, and the whole device must turn as a solid coupling.

48. When the lever *h,* Fig. 19, is in the neutral position, which is its vertical position, the friction surfaces are released,

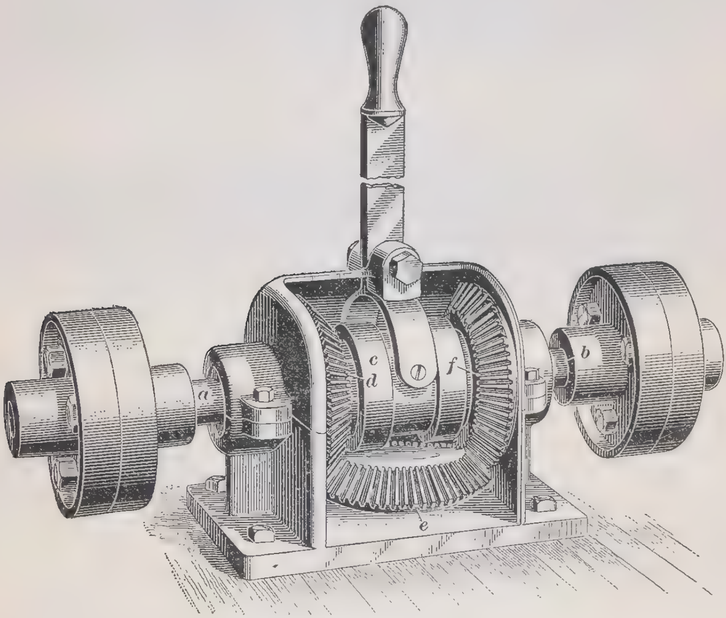


Fig. 20

the pinion gears *a* run idly, and only the case *d* revolves, so that no motion is transmitted to the propeller. The reverse motion is obtained by throwing the lever *h* backwards, or to the rear. The inclined lever *k* rides upon a double cam, which draws the brake band *l* together and clamps the outside case *d,* preventing it from revolving. The cover *c* that is bolted to *d* is also held stationary and the pinions *a* are caused to revolve in a direction opposite that in which the engine runs. The

gears *a* drive the propeller gear in the opposite direction from that in which the engine is running, and thus the reverse motion is obtained.

49. A somewhat different type of reversing gear is shown in Fig. 20. The driving shaft *a* is connected directly to the propeller shaft *b* by the clutch coupling *c* in the position it now occupies. In this position the gears *d, e,* and *f* do not transmit power, but the gear *f* turns idly on the propeller shaft. By throwing the clutch coupling to the other side, however, the shafts are disengaged and the clutch holds the gear *f* rigidly to the shaft *b,* and the direction of rotation is reversed.

50. In the type of reversing gear shown in Fig. 21 (*a*) and (*b*) the engine shaft *a* is keyed to the casing *b*. The stub shaft *c,* which is connected to the propeller shaft, is keyed to the friction cone *d,* the hub of which has a bearing in the casing *b*. The stub shaft can be moved endwise by moving the reversing lever *e,* which is pivoted at *f* and acts on the yoke *g,* held between the roller-bearing thrust collars *h*. Outside the stub shaft is a sleeve *i* that is keyed to the stationary bearing *j* by a feather key. Thus, it cannot rotate but can be moved endwise. Two pins *k* in the sleeve carry the pinions *l,* which may rotate on the pins but cannot swing around the central shaft. The pinions mesh with two gears *m* that are free to turn on the sleeve *i,* being held between collars *n* and *o*. The gears are extended to form cones *p* and *q* that may be engaged with the adjacent cone *d* and the cone on the inner surface of the casing *b*.

51. When the lever *e,* Fig. 21, is thrown over to the left, the friction cone *d* is moved to the left until its face engages the corresponding face of the casing *b,* as shown. The engine shaft then drives the stub shaft and the propeller shaft directly and in the same direction. To throw the gear into neutral position, the lever *e* is moved to the right until the cone *d* is disengaged from the casing. The engine shaft can then turn without driving the propeller. If the lever *e* is forced to the right, the inner face of the cone *d* engages the cone *p* and the whole sleeve is carried to the right until the cone *q* engages

the inner face of the cone on the casing *b*. Motion is then given by the casing to the cone *q* and its gear *m*. As the pins *k* carrying the pinions *l* are stationary, rotation of the right-hand gear *m* causes the left-hand gear *m* to turn in the opposite

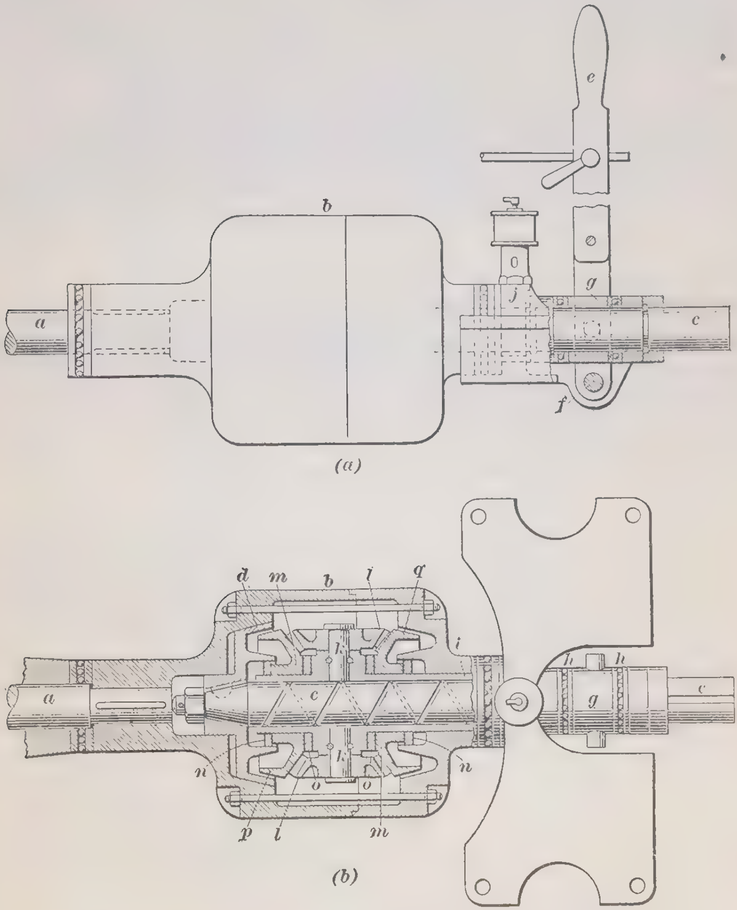


Fig. 21

direction and the same motion is communicated by the cone *p* to the cone *d*, which drives the stub shaft and the propeller shaft. Thus, the propeller is rotated in the opposite direction from that of the engine, and the motion of the boat is reversed.

SCREW PROPELLERS

52. The screw propeller is a very important part of the power equipment of a launch or motor boat. The rotary motion imparted to the crank-shaft by the gas engine inside the boat is given to the propeller outside the boat, and by its action on the water the boat is propelled forwards or backwards. Motor boats are seldom run backwards for any great distance, the backward motion being principally used when getting away from a wharf or dock, when stopping quickly, or when turning in a small space. The boat always moves more rapidly forwards than backwards, with the same expenditure of power. Propellers are made in various styles for different forms of service. They may have two, three, or four blades, which are equally spaced. The material used is generally bronze, because of its resistance to the corrosive action of salt water.

53. The form of propeller shown in Fig. 22 (*a*) is called a towing propeller, being adapted for use on heavy boats equipped with powerful engines, such a combination demanding a large blade area. The width of blade of this propeller is one-third of the diameter. A part of the surface at the back of the blade is made flat, to give effective power when the propeller is reversed. The form shown in (*b*) also presents a large surface of blade, but the outlines of the edges are sweeping curves of large radius and there are no parts of the blades that are flat. This propeller is designed particularly for high-speed motor boats, although it is also used on runabouts, cruisers, houseboats, and commercial craft. A weedless propeller is shown in (*c*). By making the leading edge *a* in the shape of a spiral receding in a direction opposite to that in which the propeller turns, and sloping the blades toward the rear, as at *b*, there is no tendency for the propeller to foul. Any grass or weeds encountered tend to slide along the leading edge toward the tip of the blade, where they are discharged, making a self-cleaning propeller. This type is useful on boats used in lakes, rivers, marshes, and other places where weeds

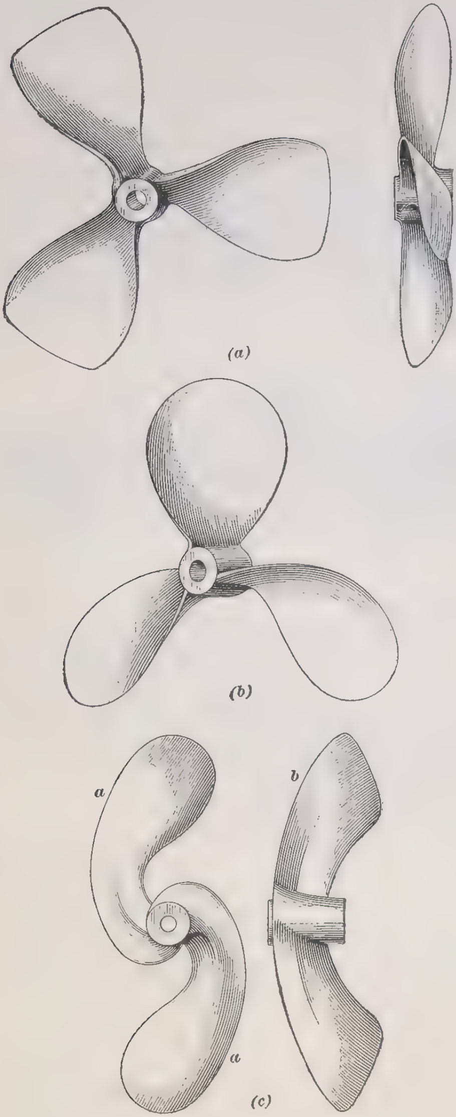


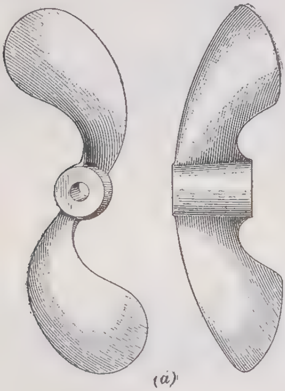
FIG. 22

may be encountered. The forms shown in Fig. 23 (*a*) and (*b*) are speed propellers, one with two blades and the other with three. Both are semi-weedless. The width of blade is about one-fourth the diameter of the propeller. These forms may be used on light boats, such as racing and pleasure boats.

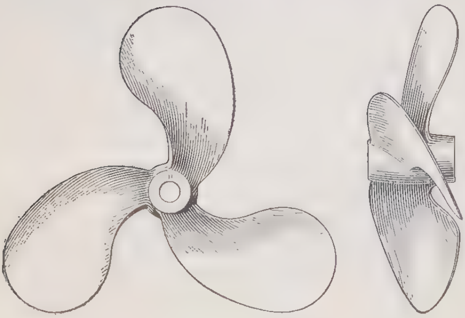
54. As the propeller turns in the water, its motion is resisted by the water, and this resistance increases with the speed of the propeller; besides, when a propeller turns very rapidly, it churns the water without increasing the speed of the boat. The speed limit of propellers seems to be reached in practice at about 800 revolutions per minute; it is probable that, at speeds in excess of 800 revolutions per minute, even in very light boats, any increase in power at the engine is more than

counterbalanced and neutralized by propeller losses. In heavy, or working, boats, the loss of efficiency at high speed is very much greater than in light boats. In heavy head winds, working boats that make but little progress with the engine running at 350 revolutions per minute will do considerably better at 20 per cent. less speed.

55. The **pitch** of the propeller is the axial, or longitudinal, distance through which the propeller would force the boat, during one revolution, if there were no resistance to the boat's forward motion, and if the propeller had no lost motion due to its revolving in a non-solid substance. The amount these losses reduce the forward motion of a boat is called the **slip.** The pitch of a propeller is measured in the same way that the pitch of a screw is measured.



(a)



(b)

Fig. 23

56. In some cases it is found expedient to use **reversing** or **feathering blade propellers.** The blades may be feathered, or the angle at which the driving surface strikes the water may be so changed that the water is driven ahead instead of astern, without reversing the direction of rotation of the propeller shaft. Midway between the ahead and the astern position is a neutral zone in which an equal

power in both directions is exerted, with no effect on the boat in either direction. There is usually but one position of the blades that approximates true pitch, and on this account there is a considerable amount of power lost in their use, unless they are very carefully designed and specially built.

57. A sleeve sliding on the shaft and connected to the blades themselves, often within an enlarged hub, or attached to it and operated by means of a lever or hand wheel inside

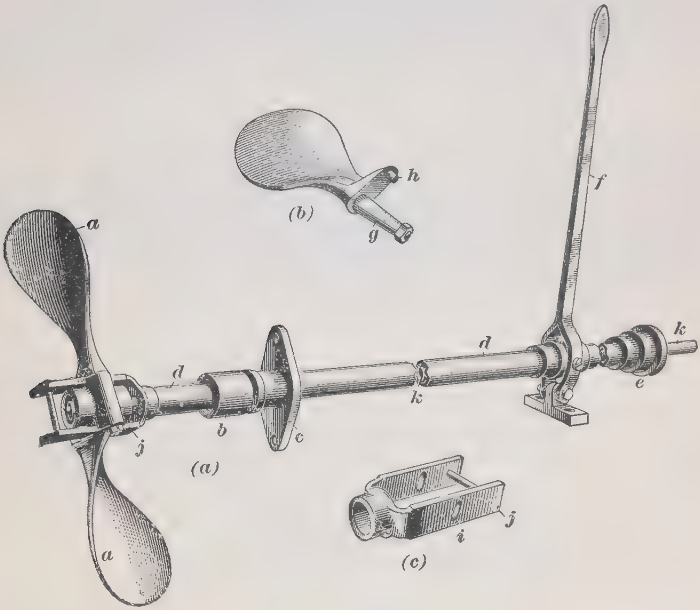


Fig. 24

the hull, is sometimes used to control the position of the blades. Such an arrangement is shown in Fig. 24 (*a*). The propeller blades are shown at *a*, the outside stuffingbox at *b*, the stern bearing at *c*, the sliding sleeve at *d*, the inside stuffingbox at *e*, and the reversing lever at *f*. One of the blades separate from the device is shown in (*b*), with the pivot *g* that fits into the hub and about which the blade turns. The pin *h* of this blade fits into the slot *i* in the fork *j*, views (*a*) and (*c*). The fork is attached to the sleeve *d*, and as the sleeve is moved forwards

or backwards the fork moves the pins so as to cause both blades to turn about their pivots. The propeller shaft is shown at *k*. The sliding sleeve revolves with the shaft, but is free to be moved along the shaft by the lever *f*.

MARINE-ENGINE OPERATION

STARTING AND STOPPING

58. Preparations for Starting.—When an engine is about to be started it is not safe to assume that all the adjustments are correct, just as they were when the engine left the shop, and only by careful examination can the operator be sure that the engine is ready for use. The following general rules may be applied whether the engine is of the two-cycle or the four-cycle type, either single cylinder or multicylinder:

First, determine which way the engine runs normally, whether right-handed or left-handed. When facing the flywheel and looking toward the stern of the boat, if the direction of rotation of the flywheel when the boat is going ahead is the same as that of the hands of a watch, the engine is a right-hand engine and requires a left-hand propeller wheel to drive the boat ahead. When the movement of the flywheel is contrary to the direction of movement of the watch hands, the engine is a left-hand engine and requires a right-hand propeller wheel in order to propel the boat ahead. When turning it over rotate the flywheel in its proper direction with the cocks open, or with the compression otherwise relieved.

59. Before attempting to start an engine, the control levers should be set so that the spark is retarded as much as possible and the throttle opened slightly. If the spark is not retarded, there may be a back kick that will injure the operator. If the engine is fitted with some form of clutch or reversing gear between the engine shaft and the propeller shaft, the lever of this gear should be set in the neutral position, so that when the engine starts it will have no external load. After the

engine has been brought up to speed and is working properly the clutch may be thrown into engagement.

60. Starting a Two-Cycle Engine.—If the engine is of the single-cylinder, two-cycle type, the easiest method of starting the engine is to prime the combustion chamber by injecting a few drops of gasoline into the priming cup with a squirt can, and turn on the gasoline supply in case a carbureter is used, priming it also by depressing the float; if, however, a vaporizer is used, set the needle valve at the point usually made on the dial when the engine is tested, swing the flywheel several times slowly back and forth through a space equal to about one-third the circumference, and then, taking hold of the starting pin, swing it up smartly against the compression in a direction opposite to its normal rotation, and then let go. If the engine does not start after trying this two or three times, close the valve in the gasoline supply, open the relief cock, and turn the engine over three or four times, and note whether or not explosions occur. The relief cocks should be open and the spark lever set so that ignition will occur either just after the center is passed or as near the end of the upward stroke as possible. By this test it can be determined whether or not there is trouble in the ignition system, and if there is, the trouble can be remedied.

61. A two-cycle engine may also be started by retarding the spark and turning the flywheel over against compression. By this method a good spark is obtained with the make-and-break system of ignition. When the engine has a very high compression it is often impossible to throw the wheel over. In this case the petcocks should be opened until the engine takes up its cycle of operations. Another way is to leave the petcocks on one cylinder closed until the engine is running.

Another way to start a two-cycle engine having a make-and-break system of ignition is to bring the wheel very hard up to compression in the opposite way in which it will revolve and snap the igniter trip. This produces a spark and the motor starts. If the motor is to be started in the reverse direction, bring the wheel up in the opposite direction and do the same.

62. When starting with a jump-spark system of ignition, the first thing to do after grasping the handle is to make sure that the spark is set late; then throw the wheel clear over. Another way is to bring the wheel hard up against compression in the opposite way from that in which the wheel will revolve and then throw in the switch, the switch having been left disconnected for the purpose. Still another method is to keep the switch connected and set the timer into a very advanced position; then bring the wheel up to hard compression and throw the timer into a late spark position, sending a shower of sparks through the mixture and starting the motor. This latter method should not be trifled with unless one is very familiar with the operation of a motor. However, all these methods should be tried, without the switch connected, until a person is familiar with them. It is a great help, when starting, to have the wheel marked in such a manner that it will show exactly when each piston is at the sparking point.

63. Reversing Two-Cycle Engines.—When there is no reverse gear, a jump-spark, two-cycle engine may be reversed without stopping the motor by bringing the timer to very late, so the motor will be running as slow as it can be kept going, then throwing the timer into a very advanced position. The engine will reverse because the advanced-spark position makes the spark occur when the piston is still rising, or on the upward stroke with engine going ahead. Because of the slowness and lack of momentum in the piston, the explosion, occurring before the piston has arrived at the center, is able to drive it back and the motor is reversed. Were the spark created when the piston was in the same place at the time of starting, the engine would start in the reverse direction.

An advanced spark is frequently used, when the engine is driving ahead, for the purpose of obtaining the extra power created by the compression of the charge just as it has been fired, the momentum of the engine being depended on to carry the piston by the center.

64. Reversing on the switch is accomplished largely by becoming familiar with the sound of the motor. In time one

can become so accustomed to its sound that the time of the beginning of the upward stroke can be distinguished when the motor is running slowly. To execute the reversal, the circuit at the switch is opened, depriving the cylinder of the spark, and the motor immediately slows down. The trained ear of the operator catches the sound of the upward stroke and the switch is thrown into contact; an explosion takes place in the cylinder and instead of completing the upward stroke the piston is pushed back with force enough to make it take up the cycle reversed. On account of its construction, the two-cycle engine runs equally well both ways.

65. Starting a Four-Cycle Engine.—Before starting a four-cycle engine, see that the inlet and exhaust valves, and also the spark, are correctly timed; that the adjustments are correct; that all the valves seat properly, and that they are not rusted or stuck in their guides. A drop or two of kerosene oil should be used occasionally on the valve stems. Be sure that all the oil cups are filled; that all moving parts are properly lubricated, that the sea cock is open, and that there is nothing to prevent the free passage of water through the cylinder water-jackets and thence outboard. Look out for mooring ropes that may be caught by the propeller; a few accidents from this cause will usually teach caution as nothing else will. Make sure that the electric-ignition system is in good working order by testing it with the current on, if of the make-and-break type, or by the buzzing at the spark coil if jump-spark ignition is used. Open the relief cocks or push the relief cams into position, turn on the gasoline and see that it runs freely, and turn the engine over two or three times as fast as convenient.

66. To facilitate starting, it is sometimes better to put a little gasoline into each cylinder through the priming cocks. This operation is called *priming*. After two or three revolutions, the engine should start, when the relief cocks should be closed or the relief cams thrown out, and the speed of the engine regulated by the throttle, the proportions of the mixture being regulated by the auxiliary air valve or by the

needle in the gasoline valve, unless a compensating or other form of carbureter is used.

67. If the engine is directly connected to the propeller, there is nothing else to be done except to get the proportions of air and gasoline vapor as nearly right as possible; see that lubrication is constant, and that the circulating water discharges freely. If the engine has a reversing gear, there will be little need of throttling when changing from full speed ahead to a neutral position or full speed astern; but with a reversing gear and no governor, extreme care should be exercised when throwing in either gear or the engine may be stopped. The reversing gear absorbs some of the power of the engine, which is more liable to stop when attempting to go astern than ahead. It will be necessary, in case a governor is not used, to have some practice in order to be sure that the engine will not be stopped when throwing in the gears, and in order to be able to handle the throttle properly. With a governor, however, the manipulation of the engine is largely a question of properly proportioning the mixture of air and gasoline vapor and of proper adjustment.

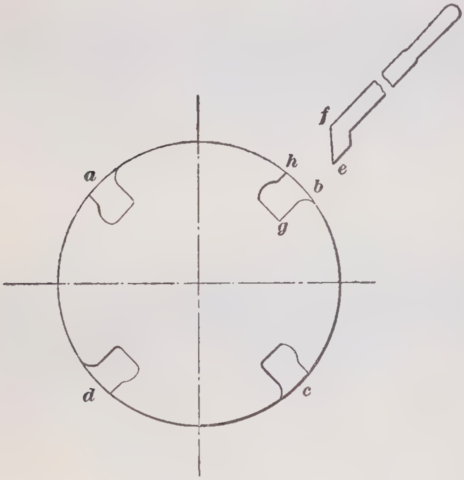


Fig. 25

68. Starting Devices.—The smaller sizes of gasoline and oil engines are started by simply grasping the rim of the flywheel and turning the engine over. In some cases, however, a starting pin is provided, which fits into a hole in the edge of the flywheel rim and serves as a handle. For somewhat larger engines a starting bar may be used. Fig. 25 shows

one method of using a starting bar. The flywheel for a single-, double-, or four-cylinder engine usually has four cored apertures, arranged 90° apart, with *a* and *b* usually 45° ahead and back of the upper center, respectively, and with *c* and *d* diametrically opposite *a* and *b*. There are two rows of these if the engine is designed to be run in both directions. In right-handed action, the lever has a toe *e* that comes against the side *g*, with the heel *f* against *h*. As soon as the engine starts, the lever is easily withdrawn; this is, perhaps, the simplest starting-bar system. On an engine with make-and-break ignition the use of a starting bar may invite injury. In pulling up on the bar and compressing the charge the cam pushes the snap rod up and if the operator allows the engine to turn backwards the make-and-break device is apt to cause a spark and produce a back kick.

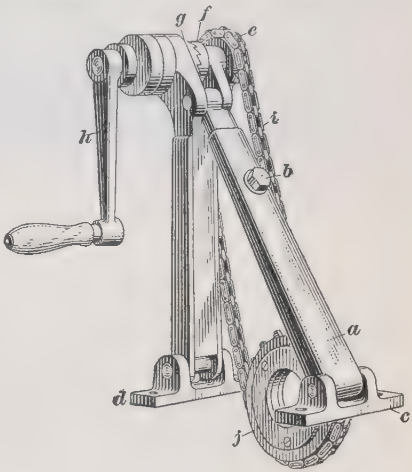


Fig. 26

69. Some makes of engines are fitted with crank starters geared to the crank-shaft by chain and sprocket wheels. One form of such starter is shown in Fig. 26. The frame *a*, which is adjustable by means of a clamp bolt *b* in each leg, is pinned to two brackets *c* and *d* that are bolted to the bed of the engine on opposite sides of the crank-shaft. At its upper end the frame carries a housing that forms a bearing for a short shaft to which are keyed the sprocket pinion *e* and one half *f* of a toothed clutch. The other half *g* of the clutch is fastened to a shaft that carries the crank *h*. A chain *i* connects the pinion *e* with a sprocket wheel *j* on the crank-shaft of the engine. When the parts *f* and *g* are engaged and the crank *h* is turned, the engine shaft is rotated. But when the engine has been started and is running, an automati-

cally operated pawl in the sprocket *j* disengages it from the crank-shaft and the chain ceases to run.

70. Stopping a Gasoline Engine.—When the engine is to be stopped, the switch should be thrown out and the oil cups shut off. When using reversing gears, it is always better to stop in the neutral position, going neither ahead nor astern, for it is usually much easier to release a clutch when the engine is running than after it has been stopped. The gasoline-supply valve, which should always be placed in the supply pipe directly back of the vaporizer or carbureter, should then be closed.

71. Among several reasons for adopting this method of procedure when stopping an engine the following may be mentioned: If the engine is stopped by entirely closing the throttle, its closed position may not be noticed when attempting to start, and with the throttle closed the cylinder will be filled with a charge of burned gas instead of a fresh charge of explosive mixture; the engine should not be stopped with the switch on and the make-and-break electrodes in contact, as the batteries will thus soon be exhausted.

72. Tracing the Cause of Failure to Start.—In a general way, when a motor does not start the first thing to do is to try the spark. This is done by turning the flywheel until the make-and-break or the timer contacts touch. Then, if the buzz of the vibrator is not heard the fault is in the ignition system. If the vibrator sounds with the usual vigor, the gasoline supply should be suspected. The needle valve of the carbureter and the valve at the tank should first be examined; if these are right a priming charge should be put into the cylinders either through the priming cups or squirted through the open petcocks from a small oil can with a point fine enough to project past the turning cock, that the charge may surely go into the cylinder. If the electric circuit is all right the motor will almost surely start after a moment and run either steadily or until the injected gasoline is used up, for this method will often bring a poor mixture into regular explosions by the heating of the cylinders. It does not all burn with the first explosion. Should the motor stop when the injected gasoline

is used up, the shortage of fuel is a surety and the tanks should be examined.

73. Causes of Refusal to Start.—The most frequent causes for a motor not starting are an open switch and a closed valve in the gasoline line either at the tank or at the carbureter.

Sometimes a new engine piston is so tightly fitted that it seems impossible to get the machine going after it has lain idle long enough to let the cylinders cool off. The condition may best be expressed by the term *frozen*. The remedy is to have the spark and all in first-class order and then to squirt into the cylinders a good spoonful of oil and work the piston up and down a number of times. Then, if the engine is primed with gasoline it will almost always start.

Many times engines have been started after long struggles by simply injecting a few squirts of oil into the cylinders. Rocking the wheel two or three times with half turns will have the effect of priming.

74. Running a Four-Cycle Diesel Engine.—It is customary for the builder of the larger sizes of heavy-oil engines to furnish a full set of instructions for the starting, running, and maintenance of his engines, and where such instructions are available they should be followed. As a rule, compressed air is used for starting Diesel engines. It is stored in steel drums or bottles at pressures from 200 to 850 pounds per square inch, and is admitted to one or more cylinders of a multicylinder engine through air starting valves. The valve in the fuel-supply line should be opened and the system should be allowed to fill with fuel. It is well to start the flow of cooling water before starting the engine; but if the water is very cold it should be allowed to flow through but slowly. Some engineers, who have experienced difficulty in starting with cold circulating water, allow the engine to start and turn over several times before permitting the flow of cooling water to begin.

75. With the drains from the air-compressor intercoolers open and the force-feed oil system in condition to take up its

operation, the valve that controls the admission of starting air to the cylinders may be opened. The engine will at once begin to turn over. It should be allowed to run on air until all the cylinders take up their regular operation, and then the stop-valve on the starting air line should be closed, as well as the drain cocks on the intercoolers. When the engine is running smoothly, the starting-air tanks should be recharged. The injection air should be maintained at a pressure corresponding to the load, as follows: One-fourth load, 600 to 750 pounds; half load, 750 to 825 pounds; three-fourths load, 825 to 900 pounds; full load, 900 to 975 pounds; and maximum load, 975 to 1,050 pounds. If the pressure of the injection air is too low for the load carried, the fuel will be imperfectly atomized and combustion will be incomplete, resulting in a smoky exhaust. If the pressure is too high, the engine will develop a knock.

When the engine is to be stopped, the clutch should be thrown into neutral position so as to relieve the engine of all load. Then the injection water to the exhaust should be shut off and the by-pass valves on the fuel valves should be opened. When the engine has come to a stop, the stop-valve in the fuel-supply line should be closed, the lubrication of the engine and the compressor shut off, and the valve on the injection-air tanks closed. Last of all, the flow of circulating water should be stopped. This should not be done, however, until some time after the engine has stopped, because there is much heat stored in the piston and cylinder walls that needs to be carried away. If the water is shut off too soon, the heat remaining will bake the oil on the cylinder walls and will cause the formation of scale in the jackets, particularly if the cooling water is hard.

76. If the engine does not start promptly after the air is turned on, it is useless to keep it running under air pressure, as the only result will be to exhaust the air in the starting reservoir. The chances are that there is air in the fuel pipes or the fuel pump, so that oil is not being admitted to the cylinders. The remedy, of course, is to fill the fuel-supply

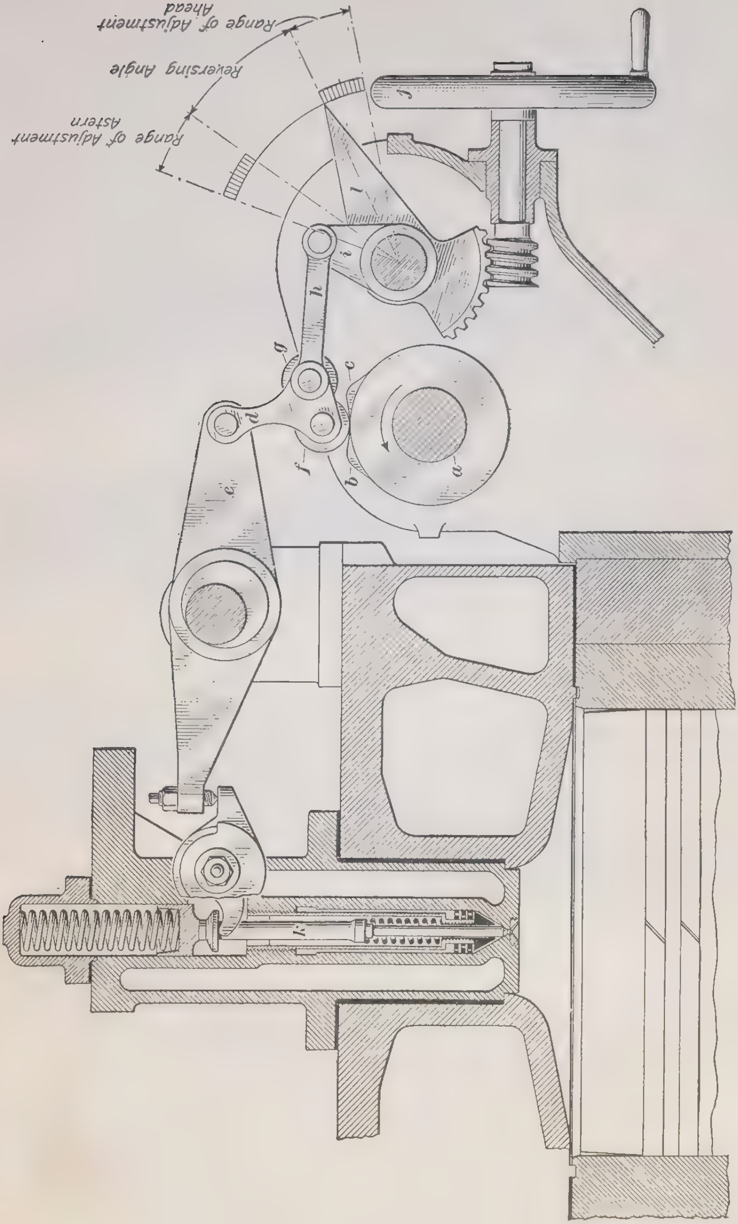

Range of Adjustment Ahead
Reversing Angle
Range of Adjustment Astern

FIG. 27

system, operating the fuel pump by hand, if necessary. In addition to too low an air pressure for injection, a smoky exhaust may be caused by overloading the engine, clogging of the fuel valve, leaky exhaust or admission valve, or an exhaust or admission valve that does not close properly because of faulty adjustment. If the air compressor fails to keep up the desired pressure, the valve in its suction pipe should be opened wider. If the engine hunts, or runs alternately fast and slow, the trouble may be traced to stiff working of the governor, sticking of the fuel-valve needles in their stuffingboxes, or unequal distribution of oil to the cylinders. The last may result from leaky check-valves or fuel-pump valves.

77. Reversing Four-Cycle Diesel Engine.—Since the valves of a four-cycle Diesel engine are actuated by cams on a cam-shaft, reversal of the direction of rotation of the crank-shaft causes a similar reversal of motion of the cam-shaft; therefore, it is necessary to have two sets of cams on the cam-shaft, one set for forward rotation and the other for astern movement. Fig. 27 shows the arrangement used on one make of four-cycle Diesel engine to accomplish the reversal of motion. The cam-shaft *a* carries the two sets of cams *b* and *c* which operate the valves for opposite directions of rotation. A swinging lever *d* attached to the valve rocker *e* carries two rollers *f* and *g*, offset in a direction parallel to the cam-shaft. The lever *d* is connected by the rod *h* to a crank *i* that may be rotated by turning the hand wheel *j*. For running ahead, the parts have the relative positions shown, and the cam *c*, rotating in the direction of the arrow, actuates the fuel valve *k* through the roller *f*. For running astern, the hand wheel is turned until the roller *g* is vertically above the cam-shaft, in which position it is acted upon by the cam *b* rotating in a direction opposite to that indicated by the arrow. The roller *f* during this time is swung out of contact with the cam *c*. The timing of the fuel valve during either ahead or astern movement may be adjusted by the hand wheel through a small range as indicated by the graduated scales over which the pointer *l* moves when the crank *i* is swung.

78. Running a Two-Cycle Diesel Engine.—Because of differences of design, the routine of starting Diesel engines of the two-cycle type differs in different engines, and so it is advisable to follow the builder's instructions. As in the four-cycle engine, air is used to turn the engine over so that it may pick up its regular cycle of operations on oil. The air is stored at a pressure of 750 pounds per square inch, or even higher, except in the case of engines having step pistons. In such a case, the area of the step piston exposed to air pressure is such that a pressure of approximately 200 pounds per square inch is ample. The step piston acts as a scavenging pump ordinarily, but when the starting lever is moved, its suction and discharge valves are automatically cut out and the step piston becomes an air motor that keeps the engine moving until the working pistons take up their normal action.

79. Running a Semi-Diesel Engine.—Since the semi-Diesel engine depends for ignition on a red-hot plate, lip, or bulb, the first step in starting such an engine is to heat the plate or bulb. This is done by means of a starting lamp, which is arranged to direct a flame on the part to be heated. The lamp uses kerosene as fuel and is built along the same lines as a blow-torch. A pressure of from 10 to 25 pounds per square inch in the starting lamp will give a hot flame that will heat the igniter bulb rapidly. While the bulb is being heated, the engine should be oiled and the lubricators set ready to work. The water supply should be started and the reversing-gear lever set in the neutral position. When the starting lamp has been burning 10 minutes the valves in the fuel-supply line and the compression relief cocks should be opened and the pump given a few strokes by hand. If smoke comes from the relief cock, the igniter bulb is hot enough; otherwise, it must be heated further.

80. If the engine is large, it will have an air starter. So, when the igniter is hot, the fuel pump should be given several quick strokes, the relief cock closed, and the valve on the starting-air tank opened. The piston should be just beyond the dead-center position. Then the air-starting valve on the cyl-

inder should be opened quickly, letting in air and driving the piston down. As soon as the flywheel has made a half-revolution, the air should be shut off; but as soon as the piston reaches upper dead-center again, the air-starting valve should be opened. This should be repeated several times until the engine fires regularly, after which the air-starting valve on the cylinder should be closed tightly. If the engine is small, the flywheel should be rocked and swung up against compression in a direction opposite to that in which it is to turn. This will cause the charge to ignite and drive the piston down, thus rotating the engine in the desired direction.

CARE AND REPAIR OF PARTS

81. Care of Pumps.—The water pumps located in the cooling system need attention at times. The packing will get worn and the suction diminish because of air getting through it. In such cases, loosen the packing nut and take out the old packing. Twine in some regularly made packing, or, what is easier, some lamp wicking of the soft stringy kind smeared with soft graphite.

82. Troubles in Water Circulation.—The lack of water in the pipes is manifested by the smell, by a smoky vapor rising from the water-jackets or the exhaust pipes, or by a difference in the sound coming from the motor. Generally, a quick remedy is to rap the valves on either side of the pump, as the main trouble is caused by particles lodging in the valves and the rapping will in most cases jar them free. If this is ineffective, the trouble may be with the screen at the inlet on the bottom of the boat. In this case, reach over the side and scrape the screen, using a long stick. If out of reach with a stick, back the boat and throw the obstruction off.

83. Laying Up Engine.—As the cold weather comes on care should be taken that after returning from a run the water is drawn off from the entire circulation. This is necessary in order to prevent freezing. When housing the boat for the winter, disconnect all pipes in which water can lodge

and blow out the water. Empty the carbureter and tanks. Put all of the electric outfit in a dry place, where there is some warmth if possible; the coils will be better for it in the spring. Take off all fittings that are movable; if prowlers can get near the boat, even the propeller will not be safe. Unscrew the cylinder head and give the inside of the cylinder a good cleaning, removing all carbon and gummed oil, particularly back of the piston rings. Open the crank-case and clean and flush it. Put on the cylinder heads, fill the cylinders with oil; the oil will not evaporate, consequently will not gum, and the finish on the cylinder walls will be preserved. Any parts of the engine that were painted to preserve it from rust should be touched up; the other parts should be cleaned of all dirt and smeared with a thin coating of grease. Throw a canvas over the whole and fasten it down snugly. Rub up the tools and smear them with grease.

84. Cleaning the motor is generally the least congenial part of power boating. It can be made more agreeable, however, by using a paint brush, with a long handle, that has been dipped in kerosene. This method enables one to reach all sorts of places otherwise inaccessible and is quick and does the work.

85. Clutch Troubles.—The principal fault with clutches is their tendency to slip. In many cases this comes from oil getting into the disks or the band, supposing that the clutches are of the dry type. In other cases the slip is from wear or because the power of the engine is greater than the clutch was designed for. The reason the clutch will not work is that when all the pressure that can be brought to bear on it is in force it is not bound hard enough to take up the load and drive the boat.

In cases of emergency, the thing to do is to release the clutch and place between the bands or the disk nails, small tools, or anything that is strong enough not to be torn to pieces when the engine is started. If they can be so placed that they will stay in position until the engine is started, and will hold their place during the moment of becoming engaged, the engine can

be started and the clutch thrown in. The object of inserting the nails or small tools is to take up the wear and force the clutch to become fully engaged before the entire compressive force is thrown upon it when the lever is pushed in.

The probability is that nothing can be made to stay between the clutch surfaces when the clutch is thrown in after the engine is started; therefore, the pieces must be inserted and the clutch jammed up solid before the engine is started. There is then no chance to reverse the clutch. Some boats carry a length of shafting made to insert in the place occupied by the clutch. If the clutch goes wrong it is taken out and the short length of shaft is inserted in its place.

86. If the engine is too powerful to be started with a fixed shaft in the ordinary way, some means of leverage should be applied to the crank to get the pistons on two of the cylinders up to and a trifle beyond compression, then the switch thrown in and a spark produced. If this cannot be done and a short tow can be secured from a passing vessel the engine will be easily started during the towing process, as the towing will not only relieve the resistance but will perhaps start the engine by the pressure on the propeller without assistance from the operator.

87. If there is no emergency, it is better not to place anything in the clutch as doing so is apt to damage the clutch. It is better to secure a tow and then send the clutch to the repair shop. A clutch slipping because of oil can be washed with gasoline, or dirt or sand may be inserted, although the latter is not good practice as it might destroy the clutch.

88. Leaky Stuffingbox.—Leaks in the stuffingbox are frequent. When packing them one should use the square packing that is provided for the purpose by the supply houses, but before putting in place the packing should have a liberal quantity of graphite spread over it. The packing should then be screwed up moderately tight. Before tightening the setnut, or locknut, the petcocks on the cylinders must be opened and the wheel thrown over, being sure that there is no spark. If the wheel turns too easily, the stuffingbox can be

set up a trifle tighter. If the wheel turns hard, the stuffingbox should be loosened until the wheel feels right. The stuffingbox should be set a little stiff on account of subsequent loosening.

89. When on a trip it is sometimes necessary to renew the packing. In such cases, when tightening up care must be taken not to strip the threads or the regular packing will not stay in. Should the threads be stripped, the box may be packed by smearing some shredded marlin or cotton waste with grease or graphite and pressing small threads of this packing between the shaft and the box with the point of a knife. In order to do this the stern of the boat should be run up on the beach, but the part of the stuffingbox that was uninjured may be packed with the regular packing. With an inside stuffingbox it is not necessary to haul the stern of the boat up on the beach to get at it. After setting up on the stuffingbox nut the amount of resistance to cranking will tell if the stuffingbox has been set up too tight.

90. Sand in Stuffingbox.—It is bad for the engine and for the shaft to send the boat through mud or sand and particularly to back it through, as is the habit with some when a spot that is just too shoal for the boat is encountered. The backing of the boat through sand is in reality dredging a channel with the propeller. During the process sand is thrown into the water circulation and works into the stuffingbox, much to the detriment of both. A little sand in the stuffingbox will cut the shaft so quickly that the propeller will be wobbling in a short time. The result is such vibration and strain that the shaft will need to be replaced or reversed.

91. Knocking or Pounding.—Aside from the knocks produced by loose bearings or preignition, a loose flywheel will produce a sound as if the bottom of the boat were being pounded out, but it is not so serious as the sounds indicate. However, before going out for another run it should be attended to. Generally a resetting of the key is all that is needed and the flywheel may be set up tight by the operator.

The pump eccentric may cause a knock for want of grease. The pump may knock because of the packing being too tight; or for want of a few drops of oil being poured into the packing.

The loss of a ball or two in the thrust bearing may produce a knock. If missing, the balls should be restored at once.

92. A shaft out of true will make a pound. It may be learned if this is the cause by watching the shaft as it revolves. When out of true the shaft must be taken out and straightened. A bend in the shaft can be discovered by stretching a length of strong linen or silk thread along the shaft, holding the ends taut over the ends of the shaft. The shaft may be straightened by laying it on a long straight stick of timber with the bent side of the shaft arching upwards and hammering it with a sledge, holding a block of wood between the shaft and the hammer. A block of wood about 3 inches by 4 inches will answer. By repeatedly testing the shaft with the thread it will be found that a few minutes will suffice to do work as well as can be done in a shop.

It may be well now to examine the ends of the shaft and see whether it has become scored at the stuffingbox. If it has, the shaft should be turned end for end, if possible, or renewed.

93. During a run one or more of the propeller blades may have been bent by coming in contact with a log or other obstruction. The blade, being of soft metal, will bend easily. The result is apt to be more or less of a pound and a pronounced vibration. Nothing can be done but get into the nearest harbor as soon as possible and have the propeller taken off. The blade can then be bent back to place, or nearly so, by laying it on a heavy block of wood and straightening it with a hammer, interposing another piece of wood between the hammer and the blade.

The bolting to the base of the motor will sometimes work loose and cause a pound. This will also cause lack of compression in the base.

Loosening of the engine-bed bolts will create either a pound or excessive vibration. If the bolt holes or lagscrew holes have worked large it is better to put in new bed pieces.

Back pressure, from the outboard end of the exhaust being suddenly depressed as in wave motion or by having too much weight on the stern, will cause pounding. Too much water lying in the muffler will cause a pound each time the gas forces itself through the water.

94. Propeller Racing.—In a sharp head sea as the boat lifts over the crest of a wave and begins the downward plunge the propeller will come out of the water and being relieved of the resistance the engine will race at terrific speed and is consequently damaged. If the sea is of such a nature that this is liable to happen frequently, the course should be changed so as to send the boat over the crests in a diagonal direction. In doing that, the strain on the engine, also the boat, is lessened and the rearing and subsequent fall and pound are very much modified. After the boat has been on the new course for a while, the proper course to be run can be maintained by shifting the course so that the seas will be on the other bow. In this way the boat beats to windward the same as is done by a sail boat.

95. Crank-Case Requirements.—The crank-case must of necessity be air-tight in a two-cycle engine, for in it the fresh charge of mixture is to be compressed. To be efficient it must also be free from excess oil, and should be entirely free from sediment. Sediment in the crank-case will be picked up by the lower end of the connecting-rod in its revolutions and carried by the splashing to the sides of the piston, and by the piston to the walls of the cylinder. Smoke issuing from the crank-case indicates that the crank-case is not air-tight and that the piston is leaking exploded gas past its rings from the cylinder.

96. Explosions in the crank-case of a two-cycle engine are due to a lack of fuel in the mixture and are caused in the same manner as back firing in the inlet pipe. All crank-cases should have a drainage cock so that they can be cleaned frequently. Where the chamber is bolted together horizontally through the center, the joint may be made tight by coating both sides

of the gasket with graphite. The oil in the crank-case should rise high enough to be ½ inch deep on the lower ends of the brasses on the connecting-rod.

97. Cleaning the Crank-Case.—In many cases, the crank-case of a two-cycle engine will become so filled with oil, gasoline, and dirt that a proper mixture is impossible. It should first be drained by means of a drainage cock, or a nut, at the bottom, which may be opened or taken off. It should then be flushed out well with kerosene to clean it of dirt and grit. When the cleaning operation is over some oil should be put into the case so that the connecting-rod can splash it up and oil the brasses, otherwise the brasses may be burned out. A handy way to take the excess oil out of the crank-case is by means of long-stemmed squirt guns, or syringes.

98. Loss of Base Compression.—In two-cycle motors, there may be loss of compression in the crank-case where the shaft enters and leaves the base. The check-valve in the base of two-port, two-cycle motors may not seat well because of dirt, carbon from base explosions, or from a weak spring, thus causing loss of compression. There should be from 2 to 5 pounds compression in the crank-case according to the design of the engine. If there is not, the mixture, which is drawn into the base and compressed, will not be forced into the cylinder with enough vigor to expel all the burned gases. This will leave the next charge so weak that it will explode weakly or not explode at all, or, it may explode so slowly that the fire will linger until the next charge is entering the cylinder and, by firing it, cause a back fire into the crank-case or the carbureter.

The loss of compression may be due to leaky gaskets of the crank-case, which may be worn or may have been frayed when the parts were bolted into place.

TROUBLES AND REMEDIES
(PART 1)

FAULTY OPERATION AND ADJUSTMENT

SYMPTOMS, CAUSES, AND CORRECTIVES

ENGINE-STARTING AND RUNNING DIFFICULTIES

1. Defective action is sometimes due to causes so apparent that explanations are unnecessary; hence, for the sake of convenience, all these possible sources of trouble have been grouped under the headings Causes of Refusal to Start, Causes of Misfiring, and Causes of Weak Explosions. In each case, the cause of the trouble may generally be traced in the last analysis to faulty ignition, a faulty mixture, or an insufficient supply of mixture. These broad causes have been stated first, and the principal mechanical or electrical defects that produce the trouble are taken up afterwards. It will be understood that these do not comprise all the possible troubles with engines. In particular, they omit entirely such matters as preignition, knocking, and overheating. The object of the following suggestions is to assist the user in tracing the difficulty when his engine refuses to give its normal power through some trouble, the nature of which is not easily determined.

2. It is a familiar fact that the internal-combustion engine is far more liable to stoppages and weaknesses, for reasons at first mysterious, than is the steam engine. The explanation of this is that, while the steam engine is purely a mechanical

apparatus, the internal-combustion engine is partly mechanical, partly chemical, and generally partly electrical in its functions. The chemical and electrical parts of its organism may go wrong through causes not connected with the visible mechanism, or—as in the case of a badly adjusted trembler, a poorly working timer, or a leaky float—through mechanical derangements so slight as to escape notice.

3. To manage successfully an internal-combustion engine—especially one that works under such a variety of conditions, often very severe, as does the automobile or the aeroplane engine—it is first of all necessary for the operator to make good use of his reasoning faculties. The symptoms of trouble, when taken singly, are often such as may be caused by any one of several possible defects; in nearly every case the defect, whatever it may be, will produce several symptoms, a careful study of which will lead to the elimination of causes that do not tally with all the symptoms; as, for instance, causes affecting all cylinders when only one or two are misbehaving, or vice versa. When the user has reached this point, generally a short further investigation of the points at which he has found trouble of that particular sort is most likely to occur, will lead him to the discovery of the true cause. The cause of loss of power, due to such faults as a loose battery connection, a sticking inlet valve, or a bit of dirt in the carbureter, will at once be recognized in its true character by the experienced operator. The only way to attain final proficiency in these things is by extended experience with the particular engine in hand; but, on the other hand, there is absolutely no excuse for the aimless groping of many inexperienced users, who will often send needlessly for a tow, or will pull an engine to pieces in their search for some simple fault that might have been located by intelligent diagnosis.

4. Causes of Refusal to Start, or of Sudden Stoppage.—The fundamental reasons for an engine refusing to run, or of a particular cylinder refusing to work, may be summed up as due to (*a*) no spark; (*b*) no mixture; or (*c*)

wholly wrong mixture. These cover all the possible causes, which may be enumerated as follows:

1. Switch not closed.
2. Gasoline not turned on.
3. Carbureter not primed, or (rarely) primed too much.
4. Weak battery.
5. Gasoline stale or mixed with kerosene.
6. Gasoline too cold to vaporize.
7. Dirt or waste in carbureter or gasoline pipe.
8. Mud splashed into air intake.
9. Water in carbureter.
10. Soot on the spark plug or contact igniter.
11. Water on spark plug.
12. Broken spark-plug porcelain.
13. Grounded wire (generally secondary).
14. Broken wire (generally primary), or loose connection.
15. Very bad adjustment of the coil tremblers.
16. Defective spark coil or condenser (rare).
17. Broken igniter spring.
18. Broken valve stem, spring, or key.
19. Wrong valve timing.

5. Causes of Misfiring.—The principal cause of misfiring is irregular sparking, which may be due to a variety of causes. Irregular sparking may be caused by the following:

1. Soot on spark plugs or contact igniters.

2. Weak battery.

3. Broken wire, making intermittent contact through the vibration of the car (generally found in the primary circuit).

4. Loose connection to binding post (generally found in primary circuit).

5. Wire occasionally grounded through vibration. This is generally found in the secondary circuit, and it is not necessary for the bare wire to make contact with the metal into which this secondary current is escaping. If the insulation of the secondary cable is weakened, and the cable is lying loosely on a metal part, the spark will often jump through the insulation.

6. Timer or circuit-breaker contact surfaces roughened by sparking.

7. Wabbling timer.

8. Poor trembler adjustment.

9. Trembler sticking at high speeds, due to inertia of heavy armature.

10. Insufficient pressure on timer contacts.

11. Unequal gaps at the points of the spark plugs. This is usually noticeable at very low engine speeds.

12. Circuit-breaker points too far apart.

13. Unequal tension of valve-closing springs.

A sticking inlet valve, which stays open when it ought to close, will cause irregular firing and occasionally back firing. Another possible cause is a very lean or rich mixture ignitible only by a strong spark. It can always be distinguished from ignition troubles by the fact that the explosion impulses, when they occur, are of much less than normal strength. If the mixture is too weak, the explosions are likely to occur every other cycle.

6. Causes of Weak Explosions.—The causes of weak explosions are as follows:

1. Mixture too lean or too rich.
2. Leakage of compression.
3. Mixture diluted by exhaust gases.
4. Spark timing later than it should be, in one or all cylinders.

If the trouble is in the mixture, the explosions would be regular, unless the mixture is so far defective that it sometimes fails to ignite in spite of the spark occurring regularly. The same will be true in any case where, as is usual, the cause of the weakness is unconnected with any irregularity in sparking.

The principal causes of weak explosions may be enumerated as follows:

1. Dirt or waste in carbureter or gasoline pipe, causing weak mixtures.

2. Stale gasoline.

3. Air intake partly obstructed, causing rich mixture.
4. Bad carbureter adjustment.
5. Trouble with float.
6. Choked muffler.
7. Lack of oil on piston, or too thin oil.
8. Leak through valve (generally the exhaust valve).
9. Leaky spark plug.
10. Valve timing wrong. This is most likely due to the fact that the cam-shaft, etc., have been taken out and replaced with the gears in incorrect angular relation. It may, however, be caused also by wear of the cams, push-rods, or valve stems, by spring in the cam-shaft or valve-lifters, or by the slipping of cams.
11. Broken or worn piston-rings.
12. Weak battery or weak magnets on magneto.

7. A two-cycle marine engine may be running along smoothly and begin gradually to slow down. This condition may be caused by too much or too little gasoline; the ignition devices may be out of order; there may be too little cylinder or other lubrication or too little water circulating through the cylinder jacket; something may be caught in the propeller wheel; in cool or cold weather, the moisture in the atmosphere may have become frozen by the rapid evaporation of the gasoline, thus preventing the free flow of air or the proper seating of the valve in the vaporizer controlling the gasoline supply and the flow of mixture from the crank-chamber; the piston and rings may have been fitted too snugly, causing them to bind in the cylinder, which may have become distorted by the different temperatures to which it is subjected, there being a comparatively cold inlet on one side of the cylinder and a hot exhaust port on the other; the exhaust ports, piping, or muffler may have become partly stopped by water, carbon, salt, or other deposits.

8. The remedies for slowing-down troubles due to the causes just mentioned will in practice suggest themselves. In many cases, the cause of the difficulty can readily be determined and overcome. For instance, trouble due to an insufficient

quantity of cylinder oil or circulating water might be attended to readily without stopping the engine, or a temporary stop might be made to remove a rope, grass, etc., from the propeller, or foreign matter from the sea-cock strainer or pump check-valves, or to adjust the ignition or replace a broken or weak valve spring.. Structural troubles, such as tight pistons and distorted cylinders, would have to be attended to at some more opportune time.

9. If the vaporizer should freeze, it may be necessary to run the engine a while and then give the accumulation of ice and frost a chance to melt. If the water supply is insufficient and the jacket becomes overheated, it may be possible in case of an emergency to continue running by using a hand pump connected with the supply; or, with the supply open water may be pumped through or poured into the water discharge. In such case, the transformation of the water into steam might make it a little dangerous for the operator, and should the clyinder be too hot, contact with water might possibly crack the cylinder.

10. Irregular running of two-cycle engines may be caused by back pressure in the exhaust, or it may be due to improper location, with reference to the exhaust port, of the transfer, or passover, port connecting with the crank-case. As a result of such improper location of the port, the engine cylinder might not be thoroughly scavenged of burned gases at high speed, when it would slow down to normal speed or slightly below, and, getting a better mixture at that speed, would speed up. It might also be caused by the exhaust ports opening too late or the inlet ports opening too early. It is well known that, with no thought of fuel economy, two-cycle engine ports should open much earlier when designed for high than for low speed, in order to more thoroughly get rid of the products of combustion. When it is discovered that the engine is being run at a speed in excess of that to which it is best adapted, the remedy is to make the ports open earlier, or hold the engine to slower speed by increasing the diameter, pitch, or blade surface of the propeller.

11. Should the engine, without missing explosions, begin to increase its speed, and then miss explosions and slow down, one would naturally be led to suppose the cause of the trouble to be insufficient length of contact of the sparking device as well as poor scavenging of the cylinder.

Trouble from loss of compression in the combustion chamber, whether in a two-cycle or a four-cycle engine, must be remedied before the engine can be made to run satisfactorily. If, in attempting to start, it is found that there is no compression, the valves should be examined to see whether they seat properly and are timed correctly. Loss of compression may be caused by a leaky gasket, allowing the pressure to leak into the water-jacket, which is the first place to look for the cause of trouble after examining the valves. A leaky gasket may sometimes be discovered by noting whether or not pressure escaping into the water-jacket shows at the water discharge.

KNOCKING, OR POUNDING

12. Undoubtedly the sense of hearing is more useful in detecting irregularities in the running of an engine than any other sense. By means of the sounds produced, the engine talks to the operator, and with a little intelligent study he will soon understand the language. Even at a distance it is often possible to tell whether an engine is running regularly or whether, as indicated by the sound of the exhaust, some of the charges admitted to the cylinder are expelled without being exploded. Standing in close proximity to the engine, the operator may distinguish a variety of sounds indicating defects about the engine and calling attention to the necessity of applying proper remedies at the first opportunity.

13. A sharp, knocking sound in stationary engines may be due to any one of the following causes:

1. Lost motion in the bearings of the connecting-rod, either at the crankpin or the piston-pin end.

2. Lateral movement of a piston-ring, the groove in the piston having become widened by wear.

3. A loose key in the flywheel or pulley.

4. Lost motion in the gears, causing the gear-shaft to be retarded in its revolution for a fraction of a second when the exhaust or inlet-valve cam hits the roller and lever.

5. Piston or cylinder worn to a considerable extent, causing an up-and-down movement of the piston, known as a piston slap.

6. The piston having worn a shoulder in the bore of the cylinder, and striking the shoulder if any play in the bearings is developed.

7. The piston striking any foreign body that may accidentally have been drawn into the cylinder.

14. Knocking in automobile engines may be due to looseness or rattle in some external part, owing to nuts having worked loose or to bolts being sheared off or being too small for their holes. Knocking due to such causes is readily detected by a careful inspection while the engine is running, and this inspection may be aided by laying the hands on parts suspected of being loose, when vibration will easily be felt; also by careful scrutiny with an electric flashlight for evidences of movement where two parts are bolted together.

15. About the most likely place to find looseness of this description is in the holding-down bolts that hold the engine to the frame on which it is mounted. Looseness at this point should be remedied at the repair shop, as it always necessitates the substitution of larger bolts, aided perhaps by dowel-pins; and in the case of the bearing cap it may be necessary to make a wholly new cap, with proper tongues fitting into grooves that must be machined or chiseled in the pillow-block.

16. A more probable cause of knocking is looseness due to wear in the main-shaft bearings, crankpin bearings, or the wristpin bearings. In a four-cylinder vertical engine, the main-shaft bearings may be quite loose without causing a knock, because the weight of the shaft and flywheel holds the shaft down; but a horizontal engine will, under certain conditions of speed and load, pound with a small amount of looseness. Only a very limited amount of looseness should be per-

mitted in the main-shaft bearings of any engine, both on account of the danger of springing the shaft and because a bearing worn beyond this extent is liable to begin cutting, as it is difficult to keep sufficient oil in it.

17. Looseness in the flywheel bearing of a vertical motor is disclosed by putting a jack under the flywheel and working it gently up and down. In the case of a horizontal engine it is necessary to move the shaft approximately in line with the pressure of the explosions, and a lever will have to be applied to the flywheel or shaft in whatever manner seems most practicable. Occasionally, looseness of the shaft can be detected by rocking the flywheel back and forth against the compression in the cylinder.

A novice should not attempt to refit the main-shaft bearings, as this requires a good deal of skill and experience for its correct execution.

Wear in the crankpin bearings is disclosed by setting the cranks at about half stroke, and rocking the shaft back and forth.

18. Knocking in the wristpin, due to wear of the pin and its bushing, is not among the commoner troubles, and it does not need to be attended to at once unless it is very bad. It is well, however, not to neglect it too long, as the bushings and the pin will be worn out of round, so that they cannot be used. A good engine will run a car several thousand miles before any replacement is demanded at this point. When it is taken out, the wristpin should be calipered all around. If it is out of round, it should be ground true; or, if this is impracticable, a new pin will have to be supplied, and the bushing reamed or scraped to fit. This, of course, should be done in a repair shop. When the wristpin has its bearings in the piston casting and is held rigidly in the small end of the connecting-rod, the holes in the piston are usually not bushed. Hence, when there is excessive wear between the wristpin and piston, the best repair is to install both a new piston and wristpin. The holes in the piston may, however, be bored out to a greater diameter and oversize wristpins fitted. If the oversize pin cannot be

obtained from the manufacturer it can be made in a machine shop. Machinery steel should be used case-hardened to a depth of about $\frac{1}{8}$ inch, and then ground. Usually the use of a new piston and pin will be cheaper.

19. A cause of knocking occasionally found is due to the wristpin and the crankpin not being quite parallel. This causes the connecting-rod to oscillate from end to end of the wristpin and crankpin bearings; and if, as is customary, there is end movement in these bearings, the knocking may be quite noticeable. If, as is likely to be the case, it is impossible to make the pins parallel, the only recourse is to take up the lost motion at the end of one or the other bearings, and possibly both bearings, by the use of washers or cheeks soldered to one end of the bushing and brasses. This is not a common cause of knocking, particularly in the better class of engines.

20. The best method of securing flywheels to short shafts is to bolt them to flanges instead of keying them. In old engines, it is sometimes found that a flywheel is held on by a common key, or by two keys 90° apart, and frequently it will work loose on its keys. This will inevitably result in a knock, which will be very loud if the engine has less than four cylinders. The crank-case should be opened and the cranks blocked so that the shaft cannot turn, and then force should be applied to the flywheel to disclose the looseness, if any. Sometimes the flywheel will be so tight on its shaft as to resist turning in this manner by using any ordinary force. In this case, it is best to take the wheel and shaft to a repair shop if a thorough search has failed to disclose any other cause for the noise. In practically all modern high-speed engines, the flywheel is bolted to a flange forged in one piece with the crankshaft. It may be possible for the bolts to become loose, in which case the flywheel will rock and pound the holes out of round. This condition is remedied by reaming or drilling the holes to the next larger standard size and fitting larger bolts.

A sprung shaft will always cause knocking, and also rapid wear and cutting of the bearings.

21. Besides the foregoing mechanical causes of knocking, there is a class of what may be called *combustion knocks* that are altogether distinct from the preceding, in that they may occur without appreciable looseness in the bearings, and are due to excessive rapidity of combustion, coupled generally with too early ignition, the charge being completely burned before the piston has reached the end of the compression stroke. Combustion knocks are due to a variety of causes, the most obvious of which is simply too early ignition. Such a knock is easily produced by running a car up a hill without suitably retarding the spark.

22. Pounding in particular cylinders of a multicylinder engine may be due to unequal rapidity of combustion, which itself may be due to unequal charges, as when the valves are unequally timed, or to irregular spark timing, such as may result from a wabbling timer or badly adjusted vibrators. If the timer contact surfaces have been roughened by sparking or by wear, they will cause the contact maker of the timer to jump when running fast, and therefore to make erratic contact, resulting in irregular firing.

23. The classes of combustion knocks just mentioned are easily traced to their causes. The knocks are not necessarily violent, and they may sound a good deal like the knocks due to loose bearings, except that, if caused by faulty action of timer or vibrators, they will occur irregularly instead of regularly.

There is, however, another and very common sort of knocking due to spontaneous ignition of the charge before the spark occurs. This may be caused by overheating of the motor from lack of water or other trouble with the circulation—a trouble at once indicated by boiling of the water in the radiator or by smoking of the exterior of the motor. It is a temporary phenomenon, and involves no harm to the motor if the latter is promptly stopped and allowed to cool.

Another, and somewhat rare, cause of the engine knocking is too high compression due to a small compression space. Such a knock can often be remedied by the use of a second gasket

between the cylinder-head and cylinder casting, when the engine is of the removable-head type.

24. Much more troublesome, and also more common, is **preignition,** as it is termed, due to a deposit of carbon in the combustion chamber or on the piston head. A carbon deposit of this nature may be caused by too much gasoline, by too much cylinder oil or a poor quality of oil, and it will accumulate gradually even with the carbureter and lubrication correctly regulated. A small quantity of carbon will give no trouble, but as the deposit thickens some portions of it will remain incandescent from one explosion to the next, and will ignite the fresh charge at some point in the compression stroke, depending on conditions. The fact that the charge is not ignited until some time during compression is due to the fact that the more highly it is compressed, the more easily it ignites.

25. True preignition results almost always, except at the highest engine speeds, in the charge being completely burned before expansion begins. It is easily distinguished, especially if the engine is taking full charges, by the resulting sound, which is a sharp, metallic *bing! bing! bing!* closely resembling that produced by a hammer striking a block of cast iron. Usually, though not always, an engine that preignites in this manner will continue running by spontaneous ignition for some seconds after the ignition switch has been opened. It can be stopped either by closing the throttle, or by shifting the gears to low speed with the clutch out, and then releasing the clutch again. The hammering due to preignition, as would be expected, is most marked when the engine is running slowly with the spark suitably retarded, and it will generally manifest itself when hill climbing, owing to the fact that the throttle is then wide open and the spark necessarily retarded to suit the slow speed of the motor.

26. In stationary engines, a heavy, pounding noise, such as is caused by premature ignition, may also be due to excessively high compression for the grade of fuel employed. In addition to its initial effect in producing a pounding noise, either preignition or too-high compression pressure may

cause the piston to expand unduly and to stick in the cylinder, which it would not do if the conditions were normal. This sticking of the piston would produce a knocking sound due to the small amount of play in the connecting-rod bearings necessary for smooth running.

A coughing or barking sound is caused by the escape of pressure past the piston, and would indicate the necessity either of replacing any worn or broken piston-rings or of reboring the cylinder and fitting a new piston.

With marine engines, a loose coupling may cause a pound, as may also a loose propeller wheel, but these pounds can easily be located.

CYLINDER AND PISTON DISORDERS

TESTS FOR COMPRESSION LEAKS

27. For a four-cycle engine, a hand test for compression can be made by cranking the engine slowly by hand and noting the resistance to the rotation that is caused by the action of the compressed charge upon the piston. Before making the compression test in this manner, however, it should be first determined how freely the engine rotates when there is no compression. This can be done either by opening the priming cocks or by removing the spark plugs, making sure that the engine is disconnected from the car, and then cranking the engine at a comparatively slow rate by hand. An engine that is in good condition can generally be rotated slowly by a light pressure of the hand on the hand crank. If the engine does not rotate as easily as this, there is too great frictional resistance to its rotation, except, of course, in possible cases of an exceedingly large engine. If this frictional resistance is very great, it will probably not be possible to make the compression test before the engine is put in proper condition with regard to its ease of rotation.

28. The following is a general outline of the method that can be employed to test the compression by cranking the engine:

Open the priming cocks or remove the spark plugs of one or all cylinders, depending on whether the engine is of the single or multicylinder type, and then open the ignition circuit for all cylinders at the switch provided for that purpose. Crank the engine slowly to determine whether or not it rotates freely and without excessive frictional resistance. If there is great frictional resistance, the engine should be lubricated to reduce the friction. If there is no reduction of friction by complete lubrication, then the crankshaft, connecting-rods, cylinders, and pistons should be examined to determine their condition. Next close the priming cock of one cylinder, or insert the spark plug if it has been removed and rotate slowly until the compression resistance begins to be felt. If the compression is good, the crank can be rocked back and forth by pulling it up well toward the dead-center position and then reducing the pull on the hand crank to allow it to be moved backwards by the action of the compressed charge on the piston. When all the parts are as nearly air-tight as they should be for proper operation of the engine, this rocking of the crank against compression can be continued for some time.

29. Another method is to pull the crank around until the compression resistance is felt to a considerable extent, and then to hold the crank stationary and note whether the compression resistance continues or decreases. By holding the crank in different positions, corresponding to a greater or a smaller degree of compression, the tightness of the piston rings in the cylinder can be tested for different positions of the piston. This, of course, can be done only when the compression space is tightly closed at all other places; that is, when there are no leaks except possibly that at the piston. This test is repeated for all the cylinders if the engine is of the multiple-cylinder type, by closing the priming cup or replacing the spark plug of the cylinder to be tested, and opening all other priming cups or removing all other spark plugs.

30. If the compression is poor, it may be due to a leak at any of the following parts: The exhaust valve, the inlet valve, the spark plug, a priming cock that is partly open or loose, the

piston, or the joint between the cylinder and the cylinder-head when the head is separate from the cylinder. It may also be due to a leaky plug that closes an opening between the bore of the cylinder and the water-jacket space, porous metal in the cylinder wall, a cracked cylinder, a cracked piston head, or a leaky valve plug joint.

31. To test for leaks around or in spark plugs, put cylinder oil or kerosene around the spark plug, crank the engine, and note whether bubbles appear in the oil around the spark plug. The appearance of bubbles in this place indicates leakage around the spark plug. A spark plug may leak between its insulation and the metal parts. Kerosene should be used in testing for such a leak. The priming cup and plugs over valves can be tested in the same manner as the spark plug.

If leaky inlet and outlet valves are suspected, it is easier to grind them in and readjust their timing, provided the valve-lifters are fitted with adjusting screws, than to devise and carry out any test to prove or disprove their tightness. Some of the modern alloy steel valves, as, for instance, tungsten-steel valves, are almost entirely free from pitting; therefore, if such valves fail to seat tightly, the trouble is almost invariably due to carbon lodged on the valve seat.

32. To test for a leaky cylinder, remove the pipe through which the hot cooling water flows from the cylinder jacket and see that the jacket is filled to the top of the outlet. Crank the engine against compression, and look for bubbles rising through the jacket water. Such bubbles indicate a leak from the cylinder bore into the jacket space. It may be possible that the bubbles come from around a plug in the cylinder wall that was inserted to close a blowhole; otherwise, bubbles indicate a cracked or porous cylinder wall in an engine whose cylinder-head is integral with the barrel. If the cylinder-head is separate from the barrel, the leak may be through the joint between these two parts.

33. To test for leakage past the piston in an engine of the vertical type, pour enough kerosene into the cylinder to cover the top of the piston completely. Crank the engine, hold it

on compression, and note whether or not any of the kerosene drips down past the piston. The crank-case will have to be open, of course, for this test. Gasoline should not be used in the cylinder, however, because it will penetrate a joint between the piston-rings and cylinder wall that is sufficiently air-tight for all practical purposes. Moreover, if gasoline is used, it will cut the oil so thoroughly from the rubbing surfaces that there is danger of their abrading and scoring when the engine is run. It may be possible to observe whether the kerosene leaks out between the piston and cylinder wall or through a crack in the piston head. In the latter case, the kerosene will come down through the inside of the piston.

SCORED AND LEAKY CYLINDERS

34. Causes of Scoring.—One of the most common causes of a scored cylinder is the running of the engine without proper lubrication. If this is continued for any length of time, one or more of the cylinders will have long vertical grooves cut into the cylinder walls, the depth of the grooves depending on the time that the engine is run without oil. Another cause of a scored cylinder is a loose wristpin. Wristpins are usually of hardened steel, and when they work loose and protrude from the holes in the piston, the sharp edge of the pins acts as a cutting tool to cut a pronounced groove in the cylinder wall. There are other causes which may be traced to imperfections of design or of machine work. These are loose core sand, imperfectly fitted piston-rings, and loosening of the pins that are used to prevent the pins from turning in the slots in the piston. Scoring may occasionally be due to the presence in the cylinder of pieces of the porcelain insulation of spark plugs, or other abrasive substance, as powdered emery, carelessly dropped into the cylinder when grinding valves.

35. Trouble from loose core sand is due to sharp sand that usually comes from the cored passage connecting the crank-case with the inlet or passover port to the combustion cham-

ber of two-cycle engines. With cylinder castings properly pickled in dilute sulphuric acid to remove the sand, this trouble would not be experienced; but with modern methods of cleaning castings by means of the sand blast, the cored passages are frequently neglected. Some engines are provided with a removable plate over the inlet port, for the express purpose of making sure that there shall be no core sand therein to cause trouble.

36. If, in an engine of the two-cycle type, the scoring consists of several parallel marks on the side where the inlet port is located, it is safe to ascribe the trouble to sand. If the scoring is on the exhaust-port side, it is usually an indication of insufficient lubrication; as the hot exhaust gases pass out they burn the oil off that side of the piston and cylinder, the exhaust side of a two-cycle engine cylinder being always hotter than the inlet side.

37. Leaky cylinders—particularly in two-cycle engines—render the wristpin, crankpin, and main-shaft bearings subject to excessive wear, because the heat of the gases that pass by the rings into the crank-case tends to burn up the oil and heat the bearings. If the engine is of the two-cycle type, the leaking products of combustion not only foul the fresh charge of gas so that it is not so explosive, but the quantity of each charge is reduced.

If, in an engine in which the inlet and exhaust valves are tight and there is no leaky gasket, it is found that the compression has become materially reduced, the trouble is probably caused by leaks from distorted, scored, or imperfect cylinders, the pistons or piston-rings being worn considerably or stuck in the slots in the piston. The only remedy is to remove the pistons for examination.

38. Repairing Scored Cylinders. — Where the scratches or scores in a cylinder are only on the surface, they may be removed by lapping, and pistons two to three thousandths oversize installed in place of the old ones. It is possible by careful work to obtain a fairly accurate degree of finish by this operation. In the lapping process an old piston

is coated with a mixture of very fine emery or other suitable abrasive and oil, and is then worked up and down in the cylinder, being rotated through part of a revolution during each up or down movement. The piston is fitted with a dummy connecting-rod, having only the wristpin bearing for attachment to the piston. Instead of an old piston, a specially constructed lead lap may be used. A lead lap made for this purpose is shown in Fig. 1. Any convenient piece of soft steel or cast iron *a* about 3 or 4 inches in diameter and a little longer than the bore of the cylinder will do for the arbor. The end *b* is turned down for a short distance so it can be gripped in the drill-press chuck for rotating the lap. The end *c* is turned to a taper of about $\frac{1}{2}$ inch per foot and the surface filed smooth. A groove *d e* is milled or planed in one side of the tapered part, being milled parallel with the taper or slightly deeper at *d* than at *e*. The lead ring is made by standing the end *c* on a board in the approximate center of some round mold somewhat larger than the bore of the cylinder and pouring melted lead to a depth of about 3 inches forming a lead ring shown in half section at *f*. The lead ring is then turned in a lathe to fit the bore of the largest one of the cylinders, if there is any difference.

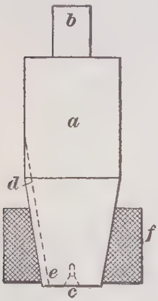


FIG. 1

39. To facilitate the lapping operation, the cylinder casting may be bolted rigidly to the table of a drill press, and the upper end of the dummy connecting-rod or the end *b* of the lead lap, gripped in the chuck of the drill press. The end *b* should not be less than 1 inch in diameter and $1\frac{1}{2}$ inches long. If it is larger than this, it will be better, if the chuck will take it.

The back gears of the drill press are thrown into action, so that the chuck revolves very slowly, and while the piston is turning, it should be raised up and down by means of the hand lever. Best results can be obtained by the combination of reciprocating and rotary motion. Good work can be done by hand lapping, but this task is much more laborious and requires

considerably more time, so the drill press should be employed when convenient.

As the lead lap wears away it can be used in the smaller cylinders, after which the lap can be expanded by driving the lead ring farther up on taper of the arbor, which may best be done by striking the end *b* on an anvil. It is well to place a wooden block in the combustion chamber for the piston to strike against at its lowest position. While the lapping operation is in progress, the abrasive material must be renewed from time to time, and the old lapping compound entirely wiped out before any new is introduced. When the operation is completed, which is indicated by bright clean cylinder surfaces from which all scratches are practically removed, all abrasive material is washed out of the cylinder by the use of gasoline, and the walls wiped clean and dry with a soft cloth.

40. In aeroplane engines, the cylinder walls are thinner than in automobile or stationary gas engines, and, hence, when the scoring or scratching of the walls is so deep as to make lapping impracticable, it is better to replace the cylinders if possible. Grinding or reboring the cylinders might reduce the thickness of the walls below a safe working point. Cylinders that have one or more deep grooves but otherwise are in good condition, are sometimes repaired by the autogenous welding process, new cast iron being fused into the groove by the oxyacetylene flame, the excess metal then being ground out to make a smooth bore. Both of these operations should be left to a workman skilled in this kind of work and having the proper equipment, and should never be attempted by a person not having the necessary experience in such work.

If the scores or scratches have considerable depth, and there is sufficient available stock in the cylinder walls, the cylinders may be rebored and oversize pistons installed.

41. Reboring of cylinders is sometimes necessary after an engine has been run for a considerable length of time, because of the natural wear between the piston and cylinder walls. If it is not convenient to have the cylinders rebored, or if the car is too old to make such an operation justifiable, the action of

the engine can usually be improved by installing new piston-rings of slightly larger circumference than the old ones. The chief drawback to this plan is that if the rings are of the proper diameter to fit the unworn portion of the cylinder bore, they will spring apart at the worn part, and the gap between the ends of the rings will be too wide. This can be overcome to a large extent by using piston-rings with long stepped ends. It is necessary, however, to have the grooves of sufficient width that there will be substantial steps on the rings to prevent breakage. The most satisfactory repair is the reboring of the cylinders and the installation of new pistons. In reboring a cylinder, care must be taken to make the bore of such size that a standard oversize piston can be used. Most manufacturers are prepared to furnish oversize pistons for their engines, there being four standard oversize dimensions adopted by the Society of Automotive Engineers for rebored cylinders. These are .010 inch, .020 inch, .030 inch, and .040 inch larger than the regular dimension.

42. A test of the diameter and roundness of the cylinder bore can be made with an ordinary pair of inside calipers, such as are used by machinists; or, a heavy wire or light rod of metal can be finished off smooth on the ends, as by a dead smooth file or an oilstone, to such a length that it will fit in the bore of the cylinder with its ends against diametrically opposite points of the cylinder wall. This solid caliper must be made just long enough to allow it to go into the smallest diameter of the cylinder bore, as found on applying it to the cylinder in different parts. It can then be readily determined whether or not the bore is smaller at the head end, as it should be when the cylinder is cool.

Instead of using the ordinary machinist's calipers, or the solid wire finished to a proper length, an inside micrometer caliper can be used. The micrometer caliper will be found more convenient by persons familiar with such tools, and it will give the exact variation of the diameter in different parts.

REFITTING PISTONS

43. Clearance must be allowed between the piston and the cylinder wall or the piston will expand by the heat and stick, because the piston is not cooled so much as the cylinder walls. The amount of this clearance must not be less than that specified by the makers of the engine and should not exceed .005 inch more than the amount specified. Lynite or aluminum-alloy pistons require nearly twice as much clearance as cast iron and aeroplane engines require more clearance than automobile engines, because they operate continuously at full load and consequently high temperature. The clearance should be greatest at the head end of the piston because the heat is greater there. The lower end of the piston should have about two-thirds as much clearance; the middle of the piston about three-fourths. A safe rule is to allow for the head end about .002 inch per inch in diameter for cast-iron pistons, and .004 inch per inch in diameter for aluminum-alloy pistons.

Steel pistons should have slightly more clearance than cast iron. The two objections to excessive clearance are the possible loss of compression, and noisy operation caused by *piston slap*. This piston slap will mostly disappear when the engine is warm. Noise is less objectionable in an aeroplane than in an automobile and should never be considered at the risk of having the piston stick in the cylinders. The loss of compression can be largely taken care of by properly fitted piston-rings and correct lubrication.

44. Examining the Piston.—When the piston is removed from the cylinder, it should be examined for deterioration. As the piston-rings are supposed to take most of the wear between the piston and cylinder, little wear should show on the piston barrel, unless it is worked out of shape and not truly cylindrical. In this case, the high spots will be worn from rubbing on the cylinder wall, while the low spots will be blackened by the leakage of gas into the crank-case. If the engine has been run without oil for even a short time, the pistons will probably be scored. If the warping or scoring has

assumed serious proportions, new pistons will probably be the cheapest method of repair. In any case, the piston must be smoothed up, and new piston-rings substituted for the old ones, as the high heat generated by the lack of lubricating oil usually causes the old ones to lose their spring or elasticity.

45. Piston-Ring Defects.—The leakage of gas past the piston-rings may be due to any of the following causes:

1. Natural wear of the rings caused by long usage, resulting in the gap between the ends of the ring becoming excessive.
2. Rings scratched or scored due to lack of lubricating oil.
3. Loss of spring or proper tension of rings.
4. Rings broken.
5. Rings stuck in grooves.
6. Slits or openings in rings lined up.

The obvious remedy for the first four causes is the use of new piston-rings.

46. Broken piston-rings are frequently the result of insufficient care in putting the piston, with the rings in place, into the cylinder. In two-cycle engines, sometimes a ring is broken by having its end caught in a port. To prevent this, engines of the two-cycle type usually have their rings pinned to keep them from turning in their grooves, the ends terminating at a point away from the port opening.

47. Ordinary one-piece piston-rings, as they wear, become open more and more at their ends, thus producing leakage past the piston; they may get so thin from wear that they finally break. Piston-rings more frequently break, however, from lack of care in putting them into the piston slots, the ring having been overstrained at some point or points, and ultimately giving way there in service. A broken piston-ring is rather hard to detect without removing the piston from the cylinder, the symptom being the same as in case of badly worn or stuck rings; that is, loss of compression.

48. Piston-rings may become stuck in the slots of the piston on account of carbon deposit; and in some cases they may become stuck so tight that they fail to expand against the cyl-

inder walls, and thus cause poor compression. They can sometimes be loosened by pouring a plentiful supply of kerosene into the cylinder with the piston standing at about half stroke, in vertical engines, and allowing it to remain there overnight. As the kerosene drains down into the crank-case, the oil therein will have to be removed and fresh oil substituted. If the pistons have been removed from the engine and the piston-rings are found to be stuck, the pistons may be submerged in kerosene for a day or so, when the rings will be loose. By working the rings back and forth, practically all the carbon deposit can be worked out of the slots of the piston.

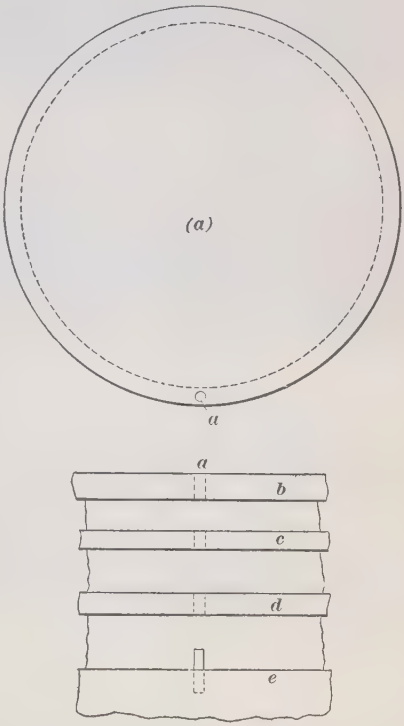
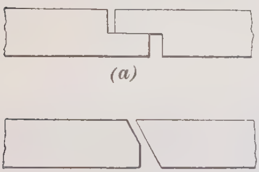


Fig. 2

The sticking of the rings may be due to water getting into the combustion chamber and causing the rings to rust in place, or the sides of the groove may be slightly tapered instead of being parallel. Where tapered sides are found, it is a good practice to straighten them up in a machine shop, and use slightly wider rings.

49. Piston-rings are sometimes held in position by small pins, one in each ring, so that the joints of adjacent rings are diametrically opposite. If for any reason these pins break, or if none are used, a ring may slip around until its joint is in line with that of the next ring above or below. This will cause loss of compression; it is an unusual occurrence, and it may be necessary to take off the cylinder to locate the trouble.

50. A good method of pinning piston-rings is shown in Fig. 2, in which (*a*) is a diagram of a piston head, the dotted lines showing the bottom of the ring slot, while (*b*) is a sketch of a portion of one side of the piston. With the piston square on its lower end, drill, at *a*, a point about half way between the inlet and exhaust ports, through *b*, *c*, and *d*, a hole large enough for clearance for a small tap, continue the hole into *e* with a tap drill, tap the hole, and screw into it a slotted screw to extend into the slot for a distance not quite one-half the width of the slot. Then tap and plug the hole through *b*, *c*, and *d* with screws dipped in muriatic acid to rust them in place, the screw plugs being in each case below the surface of the slot faces. At another point, where it will not come opposite a port, drill a hole through *b* and *c* and tap into *d*, plugging the clearance holes, as before. Drill at another point a hole through *b*, tapping into *c*. The slotted screws extend one-half or less the width of the slots from the bottom, so that, if the rings are parted as in Fig. 3 (*a*) one of the ends could be cut off slightly to receive the pin, or, if parted diagonally, as in (*b*), a space could be cut out for the pin. With this method of pinning the rings, there is no way for the pins to work out to score the cylinders. While it is customary to pin the piston-rings for two-cycle engines, pins are rarely found necessary in four-cycle engines, as such engines have no ports to catch the ends of the rings.



(*a*)

(*b*)

FIG. 3

51. The compression of an engine can sometimes be improved, even with worn cylinders, by pinning the rings in place. As the rings are not free to turn and will be confined in one position, they will soon wear to fit the contour of the cylinder. Some very satisfactory results have been obtained in this way.

52. Placing Piston-Rings in Piston.—The piston-ring grooves should be cleaned of all carbon deposit before the old rings are replaced or new ones substituted. This can be

done by scraping out the grooves with a tool that will fit in them, and then washing them out thoroughly with kerosene. Each ring should be tried in the groove to which it is to be applied. Roll the ring all the way around the ring groove, as shown in Fig. 4, and see that it enters the groove freely at all points with no side play, and deep enough so that it extends below the piston surface at every point. When piston-rings are purchased from the maker of the engine, who is usually prepared to supply them in regular and oversizes, it will be found that they are generally a satisfactory fit in the grooves and in the cylinder, and require no fitting. If the grooves have worn sideways, it will be necessary to turn them up true in a machine shop, and use wider rings. There are cases where the ring is cut just a little larger than required, making it necessary to remove enough metal from the sides to make it fit the groove in which it will finally rest. To do this, rub the ring evenly on a sheet of fine emery cloth fastened to a smooth flat surface, until the desired fit is obtained. In fitting oversize rings, they must first be tried in the cylinder to make certain that there is a small amount of clearance between the ends, and that they make good contact with the cylinder wall.

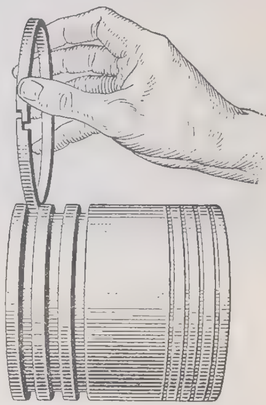


Fig. 4

If the first cost of the repair is not the most important item, so-called leak-proof or similar composite piston-rings which are marketed by concerns specializing on this type of ring, can with advantage be substituted for the ordinary single split piston-rings. The superiority of such rings over single split rings is that they will remain tight in spite of wear as long as sufficient elasticity is left in them to hug the cylinder wall; ordinary single split rings will leak more and more as they wear, and hence the compression will become poorer and poorer. Eccentric rings, or rings that are thicker on one side than on the other, are not desirable for aeroplane engines using

aluminum pistons, because the generous piston clearance leaves a narrow bearing in the grooves on the thin side of the ring, which wears the grooves more rapidly.

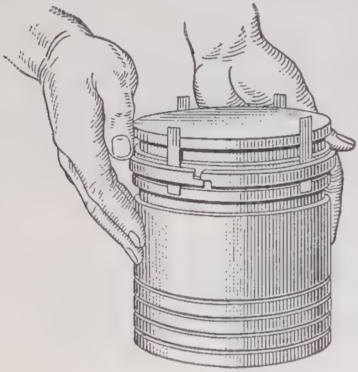


Fig. 5

53. When the rings are ready to be put in place, insert three or four strips of thin sheet metal such as tin, or brass, about $\frac{1}{2}$ inch wide and 4 or 5 inches long, under the rings as shown in Fig. 5. There must be one strip under each end of the ring, and at least one under the back. Slide the rings down over the strips as shown in the illustration, the strips being left short of the last groove so that the ring for this groove will slip in place. The bottom ring should be placed in position first, after which the others should be installed in order from the bottom up.

54. Replacing Piston in Cylinder.—When the piston is replaced in the cylinder, some device must be employed to compress the rings in their grooves so that they will enter the cylinder easily. There are several manufactured devices on the market for this purpose, but in the absence of one of these, a piece of flexible wire may be drawn around the ring and held taut until the ring is inserted, after which it is moved to the next ring and so on.

A handy instrument that can readily be made for this purpose and which will compress all of the rings at once, and thus facilitate their insertion, is shown in Fig. 6. It consists of a piece of sheet metal bent to a circular shape, with the ends shaped so as to hold a bolt by which they are drawn together. The device should be made of sufficient width to cover all of the rings of the piston on which it is to be used, and must be stiff enough to bend uniformly through-

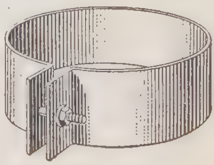


Fig. 6

out its length. A device as shown in Fig. 7 is also very handy, only one piston-ring at a time being held together.

55. If the cylinder is in good condition, an ordinary one-piece split piston-ring may be considered as having reached the end of its usefulness when its ends, on trying the ring in the cylinder, gap open more than .005 inch for each inch of cylinder diameter, unless otherwise specified by the makers. To try the ring in the cylinder, it must be removed from the piston. The following method is a good one for this purpose: Flatten the end of a rather large piece of copper wire, so that the flattened end resembles a thin screw-driver. Put the flattened end of the wire under the piston-ring at the opening, and lift the ring out of its groove just far enough for one end to slide over the piston-ring pin when the ring is twisted around in its groove by the free hand. If the pin is high enough, the ring can generally be removed from the groove by twisting it around still farther and pressing the raised end lightly sidewise, so that it cannot spring back into the groove. If there is no piston-ring pin, or if the pin is not high enough to keep the ring out of its groove, the ring can be held up by a small block of wood. This block should not be thicker than the depth of the groove. It may be more convenient to use strips of thin sheet metal instead of blocks; sheet copper or tin will answer. The strips can be slipped under the ring when it is lifted by the copper wire. Strips of this kind are useful for slipping the ring on or off over other rings or grooves. The rings should not be sprung open any farther than is necessary when removing or putting them in place, because piston-rings are made of cast iron and consequently break easily.

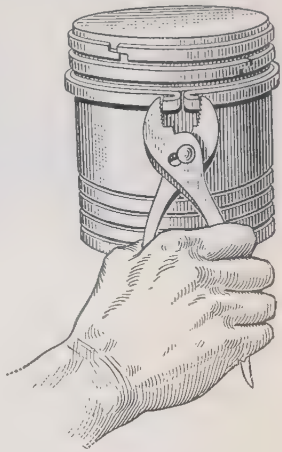


FIG. 7

VALVE DERANGEMENTS

56. Leaky Inlet and Exhaust Valves.—Trouble from loss of compression in the combustion chamber, when the spark plug is tight and there is plenty of oil on the piston, is generally due to leaky valves. In order to determine whether the leak is in the valves or in the piston-rings, a moderate quantity of oil may be squirted through the priming cocks, if any are provided on the engine, and the crank turned two or three times, which will temporarily check whatever leakage there may be around the piston. In the absence of priming cocks, the spark plugs should be removed, and the oil introduced through the spark-plug openings, after which the plugs must be screwed tightly in place. If the compressed charge still escapes, the inlet valve may be taken out and examined. The leak, however, is much more likely to be in the exhaust valve, because the seat of the latter is subjected to the eroding action of the hot exhaust gases.

57. The manner in which the valves are removed for examination depends on the design of the engine. If caged valves are used, the cages are removed from the cylinders. If uncaged valves are used in detachable cylinder-heads, the cylinder-heads are removed. To take out the valves of an engine fitted with ordinary **L**-head or **T**-head cylinders, the cap over the valve that is to be taken out is removed first. The engine is then cranked by hand, with the ignition cut off, until the valve is closed, in which position the valve-spring is under the least tension.

The valve-spring collar, against which the valve-spring rests, must next be freed from the valve stem. To do this, the valve-spring must be compressed until the key, pin, or collar that attaches the valve-spring collar to the valve stem can be removed with the fingers. The spring can readily be compressed by the use of a valve-lifter, known also as a valve remover or valve-spring lifter. This device is made in a variety of forms, and can be obtained at any automobile store or supply house.

In some engines, mainly of the aeroplane type, it is impossible to remove the valves without removing the cylinders from the crank-case, because the cylinder-head is cast in one piece with the cylinder body, and the valve seats are machined directly in the cylinder-heads. In order to grind the valves, the cylinder must be removed, as it is impossible to gain access to the valve heads or their seats otherwise.

58. One way to take out a valve is to turn the engine over by hand, with the switch off and the priming cocks open, until the valve is opened. Then prop up the valve-spring with two pieces of wood or brass *a*, Fig. 8, cut to the proper length to go between the spring collar *b* and the upper end (or lower end, if this is more convenient) of the push-rod guide *c*, and turn the engine again until the push-rod *d* is down as far as it will go. Push the valve down; the key at *e* may now be slipped out. If the props have been made accurately to length, the valve may be slipped up and out, leaving the spring and the collar in place. Inspection should show the valve seat to be of uniform appearance all the way around, and dull—not polished. If the seat of either valve is pitted or rough, or if it is worn bright on one side, the conclusion is that it has been seating only on that side, and that it needs regrinding.

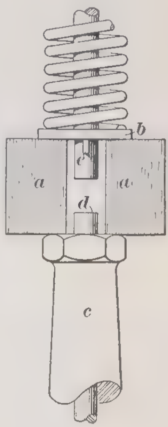


Fig. 8

59. Weak or Broken Valve-Spring.—The valve-springs should all have the same strength as nearly as practicable, so as to make the valves all close with equal promptness, because if one valve lags in closing it will make the compression in that cylinder different from that in the other cylinders, which will make the engine run unevenly and cause vibration. Sometimes a valve-spring, especially if the valve is of the automatic variety, will weaken from becoming overheated. This is almost sure to occur if the engine has been allowed to overheat from lack of water. In time, a spring loaded too near its elastic limit will break from the jarring to which it is sub-

jected. If the spring is weak or if it is broken in a single place, it will be indicated by a loss of power at high speeds—although the power may still be ample at low speeds. If the spring is badly broken, the result will be clattering of the valve and blowing back in the intake pipe at high speeds. A broken spring can be detected by a careful inspection of each spring.

60. If the engine has four cylinders, it may be possible for the inlet-valve springs to be slightly weak without the mixture blowing back at the intake, owing to the fact that one or another cylinder is aspirating all the time, and the air expelled from one cylinder is drawn into the next. One way to get around this difficulty is to block open the exhaust valves of two cylinders—the first and fourth or the second and third—while the others are tested. It will probably be simpler, however, to experiment with the valve-spring tension. If the valve-spring is weak, and if it is temporarily increased in stiffness by putting washers under it to compress it, a marked increase in the power of the motor at high speeds will be observed. The proper remedy, however, is to put in a new spring, or, if this cannot be done, to stretch the old spring.

A good way to test the spring is to place a small platform weighing scale on the table of a drill press and compress the spring between this and the drill spindle; a flat piece of sheet metal can be placed over the end of the drill spindle to form a flat surface for the spring to rest against. The feed-wheel of the drill press is then turned until the spring is compressed to the same length as it would be when the valve is closed. The amount of the pressure of the spring is then weighed. By comparing this with the average strength of three or four new springs, or the pressure in pounds as given by the makers' instructions, the condition of the spring can be ascertained.

The engine will work better if the springs are a little too stiff than if they are not stiff enough. There will also be less danger of breakage of the valve stems and keys. In assembling valve-springs, they should be compressed in a vise and tied with strong cord or wire in three or four places, to hold them in place until secured by the regular fastenings.

61. Unequal Tension of Automatic Inlet-Valve Springs.—The effect of unequal tension in the springs of automatic inlet valves is to permit one cylinder to take more gas than another. Consequently, at slow speeds the cylinder whose valve-spring is weak will get the larger charge; and at high speeds part of the charge will be blown back through the valve whose spring is weak, so that the other cylinders will get stronger impulses. A quick way to test the equality of valve-spring tension without taking out the valves is to run the engine slowly with the throttle almost closed. This will cause the cylinders whose springs are stiff to receive scarcely any gas, and the cylinders whose valve-springs are weaker will do most of the work. It is possible, however, to go to excess in a test of this sort, since, when a motor is running light with the minimum quantity of gas, one cylinder is almost sure to get more gas than another, if the inlet valves are automatic, even with the most careful equalizing of the springs. If the tension of the valve-springs is under suspicion, the valves should be taken out and the springs tested by compressing them by forcing the valve stems together.

62. Excessive Lift of Automatic Inlet Valve.—The lift of an automatic inlet valve should be proportionate to the spring tension and to the weight of the valve, so that the spring will be able to overcome the inertia of the valve, and close it before the piston has started so far on its compression stroke as to expel any of the mixture through the open valve.

The symptoms of too great a valve lift are loss of power and blowing back at high speeds. A valve 2 inches in outer diameter should not ordinarily lift more than $\frac{1}{8}$ inch and a lift of $\frac{3}{16}$ inch would be excessive for almost any valves found on high-speed engines. An excessive lift, like a weak spring, is likely to result in breakage of the valve stems and keys through unnecessary hammering of the valve when opening and closing.

63. Broken Valve Stem or Key.—Trouble from a broken valve stem or key is more likely to occur with automatic valves than with those mechanically operated. The result, if the valve opens downwards, is to let it stay open all the time,

causing that cylinder to cease work, while the sparks from the plug ignite the mixture in the intake pipe and cause explosions there and in the carbureter. If the valve, whether automatic or mechanically operated, opens upwards, it will clatter on its seat and permit much of the mixture to be expelled during the first part of the compression stroke.

64. If the valve is an exhaust valve, there is nothing to prevent it from being sucked wide open on the suction stroke, and an accident of this kind will generally cause that cylinder to go out of action entirely. The clattering, if the engine continues running by virtue of other cylinders, is likely to be marked.

65. Slipped Valve Cams.—Some cheaply constructed motors have the valve cams held on the shaft by taper pins that in time shear partly or wholly through, permitting the cams to turn on the shaft. The cams may turn a short distance and then be jammed by fragments of the taper pins. The symptom indicating trouble due to this cause is partial or complete loss of power in the cylinder affected, when nothing is wrong with the ignition, valve-spring tension, etc.; and it will be equally marked at all speeds. If a cam is pinned on its shaft, the proper way to secure it is to add another pin, or, better, to add a key to take the torsional stress, and depend on the pin only to keep the cam from slipping endwise on the shaft.

LUBRICATION TROUBLES

66. Lack of Cylinder Oil.—If the oil is cut off from the engine either from the supply in the crank-case, lubricator cups, or other sources having become exhausted, or from failure of the lubricating system to deliver the oil properly, the engine must be stopped immediately to prevent serious damage to its parts. Practically all engines are equipped with some ready means of noting the action of the oil, such as sight feed glasses and oil gauges of various types. The operator will do well to glance at these indicators frequently, as it may be the means of preventing expensive repair bills.

The first indication of a lack of oil is a sudden sluggish action of the engine with a material falling off in power. Unless the engine is stopped and examined for the cause of trouble, and the oil supplied to the cylinders, there will be further symptoms in the shape of dry, wheezy sounds, and smoking from openings in the crank-case or base of the engine. When one has once had an experience of this kind, he will never mistake the symptoms, as he has probably paid dearly for the experience. If the cause of the trouble is not determined and remedied, the babbitt will be melted out of the bearings, which will be manifested by a terrific hammering and rattling of the engine. It is extremely dangerous to run the engine after this stage has developed. There have been cases where automobiles were run with burned-out bearings in the hope of reaching the nearest repair shop, with the result that one or more of the connecting-rods were twisted off at the crank end, the crank-shaft scored or warped to such an extent that it was necessary to install a new one, and holes were broken into the crank-case. The expense of having the car towed in would have been slight compared to that required to make the necessary repairs.

The result of the lack of oil in the cylinders is the scoring of the piston and cylinder wall, and the loss of spring in the piston-rings, usually requiring reboring of the cylinders and the renewal of the pistons and rings.

67. The chief cause of insufficient lubrication is a lack of oil in the reservoir or oil cups, usually due to carelessness or forgetfulness on the part of the operator. In a few cases it may be caused by a failure to adjust the oil cups so as to allow the oil to drip sufficiently to lubricate the cylinder and piston, or by a leakage of the oil from the reservoir due to a cock which has broken or jarred open. Another, and more common, cause is an obstruction in some part of the lubrication system which prevents the passage of the oil. The stoppage may be due to leaks in the suction pipe, that is, the pipe that leads from the crank-case to the pump, in the case of circulating constant-level systems having the pump located above the oil

reservoir. This trouble is often noticed when the lubricating system has been taken apart for cleaning. The suction pipe must be absolutely air-tight, or the oil will not be drawn from the oil reservoir to the pump. When the oil pump has been removed and taken apart, it is usually necessary to prime it, or fill it with oil, when it is assembled again in order to start it working. If the pipe line is stopped up, each section should be removed separately and a wire run through it to remove any dirt or foreign matter it contains, after which it should be washed by running kerosene through it.

Whenever an engine has been without oil or when the pistons have been placed in the cylinders after having been removed, a little oil should be squirted onto the top of the piston, so that there will be sufficient lubrication between the piston and cylinder wall until the oil has had a chance to reach them from the regular sources.

68. Too Much Oil in Cylinders.—Too much oil in the cylinders is indicated by white smoke in the exhaust and fouled spark plugs and valves. The accumulation of oil on the spark plugs causes misfiring by short-circuiting the contact points. If the oil supply is not cut down promptly, there will soon be an accumulation of carbon on the piston and cylinder walls, as well as in the piston-ring grooves.

Trouble from this cause, unless entirely too much oil has been poured into the crank-case, is rarely experienced with circulating constant-level splash oiling systems, in which no means are provided for adjusting the oil level. If trouble should occur, however, the advice of the maker of the engine should be sought. In splash oiling systems, and also in pressure-feed oiling systems, in which the flywheel of the engine circulates the oil, pouring too much oil into the crank-case will give excessive cylinder lubrication. The remedy is to draw off oil until the correct level again obtains. In pressure-feed oiling systems of the high-pressure type, the relief valve of the oil pump may be set for too high a pressure, the remedy being to readjust the relief valve for a lower pressure. When oil cups are used on an engine, the feed may be such that the oil will

be given to the cylinders at too high a rate. The remedy is to cut down the feed as soon as white smoke is observed in the exhaust.

69. Where no provision is made for controlling the supply of oil to the cylinders, the amount which gets past the pistons into the combustion chamber can be diminished to some extent, by cutting or filing away part of the lower wall of one or both of the two lower grooves of the piston, as shown at *a* and *b*, Fig. 9, and drilling small holes *c* about $\frac{1}{32}$ inch to $\frac{1}{16}$ inch in diameter at regular intervals around the groove and slanting downward about 45 degrees, as shown at *d*. The larger the holes and the greater the number of them the more effectively will the oil be collected, and returned through the holes to the crank-case. It is best to begin with one groove and a few small holes and increase the number each time the engine is overhauled until the over-lubrication trouble disappears. A good way to file this groove is to use a piece of wood 2 or 3 inches in width and of the right thickness to fit snugly in the groove so it will not slip as the file is rubbed against it; then with this as a guide use the edge of the file to make the notch as shown at *a* and *b*, the notch being made about equal in depth all the way around the piston. This notch should not be more than one-fourth of the depth of the groove in which the piston-ring fits.

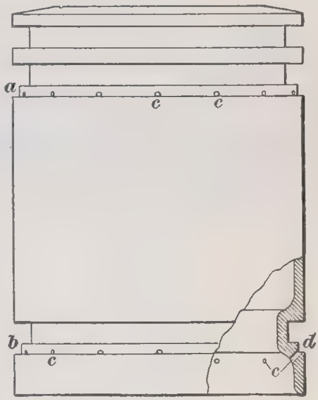


FIG. 9

70. Improper Oil in Cylinders.—The trouble symptoms produced by the use of oil unsuited for lubricating the piston are white or yellow smoke in the exhaust, rapid fouling of spark plugs, partial clogging of inlet and exhaust valves, and rapid accumulation of carbon on the valves, in the combustion chamber, and about the piston-rings.

To remedy the trouble, empty out all the unsuitable oil if possible, and substitute oil known to be good. Inject kerosene freely through the priming cock to loosen the carbon deposit on the piston-rings, and use kerosene to free the valves if they stick. Drain the crank-case, and also the splash troughs, and clean the entire system out with kerosene. Drain off all kerosene, and refill the oiling system with a good grade of cylinder oil of the kind recommended for the particular engine at hand. The carbon deposit should be removed, and the spark plugs cleaned off, after which the engine will be ready again. Considerable white smoke will come from the exhaust at first, but this will soon wear off.

COOLING-SYSTEM TROUBLES

71. Lack of Water.—Lack of water in the radiator of the cooling system of an engine is indicated by the rapid emission of steam, if there is sufficient water to enter the engine jacket; the bottom of radiator being cold; the overheating and smoking of the engine, followed by laboring, groaning sounds, owing to the oil being burned away faster than it is supplied to the pistons; and, if the engine still continues running, expansion and seizure of the pistons in the cylinders.

Trouble from lack of water is due to carelessness in not filling the tank before starting; leakage in radiator or piping; accidental opening of the drain cock at the lowest point of the circulation system; breakage of drain cock by flying stone, etc.

The remedies for such trouble are apparent on inspection. If the motor becomes overheated so that the water boils away rapidly, and there is reason to think that the upper portion of the water-jacket is dry, the motor should be allowed to cool before water is added. The water should not be poured into the radiator until the engine has cooled off to such an extent that it will not burn the hand when the hand is placed on it. Otherwise, the sudden contraction may warp or even crack the cylinders, or it may cause the cylinders to contract and seize the pistons. If the water gives out when at some distance from the nearest source of supply, it is not advisable to attempt

to drive to the source of supply, as the engine may be very seriously damaged by so doing.

72. Obstructed Circulation.—An obstruction to the circulation of the cooling water elsewhere than in the radiator will cause the bottom of the radiator to remain cool while the top is probably boiling hot.

Among the causes of obstructed circulation are a broken pump, broken driving connection to pump, or slipping belt or friction pulley, if the pump is driven in that manner. Waste or the like lodged in the pump or piping also will obstruct the circulation.

The remedies for such troubles will become obvious on inspection. If the belt or friction pulley has oil on it, gasoline may be used to clean the pulley, as well as the flywheel if it drives the pulley.

73. Scale or Sediment in Radiator.—The presence of scale or sediment in the radiator is indicated when the whole radiator becomes hot or when steam formed in the jacket forces water out of the upper pipe to the radiator, there being no oil on the inside or dirt on the outside of the radiator.

Scale will deposit from hard water if the temperature of the water is allowed to approach the boiling point. A similar scale, almost impossible to eliminate, will crystallize from calcium-chloride non-freezing mixtures if these are allowed to become supersaturated.

The formation of scale in the radiator reduces the cooling effect of the water, as the scale is an exceedingly poor conductor of heat. The formation of scale to such an extent as to become very detrimental to the cooling system can be prevented by the proper attention at regular intervals. The water should be drawn off occasionally and the entire system flushed out, by use of water under pressure from a hose if convenient. The radiator should then be filled with clean water. Every few weeks a solution of ordinary washing soda, in the proportion of a handful of soda to a pail of water, should be poured into the radiator and the engine run for a few hours. The water and soda solution should then be drawn off and the system

flushed out thoroughly before fresh water is put in. It is better to dissolve the soda in hot water before pouring it into the radiator, as otherwise the crystals would drop to the bottom.

74. A radiator that has been neglected until it has become badly choked with lime scale is practically useless, although, if it is made entirely of brass and copper, as is generally the case, the scale may sometimes be removed by the use of a dilute solution of hydrochloric acid in the proportion of about 1 part of acid to 10 parts of water. This solution should be left in the radiator long enough only to loosen the scale, after which it should be drawn off and the radiator washed out. In doing this, a good plan is to disconnect the radiator from the engine, so as to confine the effects of the acid. The scale in the water-jacket space of the engine can be loosened afterwards by filling the cooling system with a carbonate-of-soda solution and running the car, after which the scale can be washed out. Scale is not likely to deposit to any great extent in radiators that have thin, flat, vertical tubes, especially if there is rapid forced circulation of the cooling water by a powerful circulating pump.

75. Spark Retarded Too Far.—One of the common causes of overheating of the cooling system is the running of the engine for some time with a spark that has not been advanced far enough. In such a case, the explosion occurs so late that there is only a small drop in the temperature of the burning charge between the time that ignition occurs and the time that the exhaust valve opens; consequently, the heat due to the burning charge is much greater than is the case with a properly timed, early ignition, and the cooling system becomes unable to carry the heat off as fast as it is generated.

The obvious remedy is to run at all times with the spark advanced as far as conditions will permit.

76. Fan Troubles.—A simple trouble, but one likely to be mistaken by the novice for radiator or circulation trouble, is the slipping of the fan belt. The belt should be tested occasionally, and not allowed to get so loose that the fan pulley can spin inside it. It does not have to be tight. If the fan does not run at full speed so as to draw air through the radiator and

force it against the engine with sufficient rapidity, the cooling water may become so hot as to allow the cylinders to overheat. In practically all modern cars using a belt-driven fan, the fan bracket can be adjusted readily so as to keep the fan belt tight; hence, if the belt is found to be slack, the fan bracket should at once be shifted until the belt is tightened sufficiently.

A fan will stop entirely on account of a broken belt or a broken gear. In an emergency, when a fan belt is broken so that it cannot be repaired, or has been lost after breaking, the fan may be driven temporarily by means of either a strong piece of cord or a piece of rawhide belt lacing. The latter, cut into strips, can be purchased from dealers in belting and mill supplies. Cord such as is used for chalk lines in carpentry or for deep-sea fishing can generally be purchased of any hardware dealer. It may be necessary to put on several separate bands of the cord or belt lacing in order to drive the fan at full speed.

77. Radiator Hose.—The hose used for connecting the metal tubing should be heavy enough so that it cannot collapse by the suction of the pump, and of good enough quality, or be renewed often enough, so that none of the rubber or fabric can work loose. It should fit the metal pipe properly and be firmly clamped with good-fitting hose clamps. The hose should be slipped over the end of the metal pipe carefully or the inner fabric of the hose is liable to be loosened, and may fold under and partly or entirely stop the circulation of the water. The gaskets must be so placed as not to project on the inside and reduce the area of the water passage.

78. Antifreezing Mixtures.—There are three antifreezing substances commonly used: Wood alcohol, glycerine, and calcium chloride. The objection to the last is that it deposits scale in the radiator and other water passages. Alcohol vaporizes rapidly and must be often renewed, and glycerine affects the rubber of the hose connections. A mixture of alcohol and glycerine in proportion of 1 quart alcohol, 1 quart glycerine, and 4 quarts water is recommended for a temperature not exceeding 10 degrees F. below zero, but more

alcohol must be added from time to time to make up for evaporation. When glycerine alone is used, one part glycerine to three parts of water is a common mixture.

CARBURETER DISTURBANCES

PROPORTIONING OF MIXTURE

79. Overrich Mixture.—If a mixture is very rich, that is, if there is an excessive amount of gasoline in the charge, black smoke will appear in the exhaust. If the mixture is too rich, but not rich enough to produce smoke, it will still produce an acrid odor in the exhaust, and will cause overheating of the radiator, unnecessary sooting of the spark plugs, accumulation of carbon in the combustion chamber, and unnecessarily rapid consumption of gasoline, with diminished power. An automobile of from 12 to 20 horsepower, running at an average speed of 20 miles an hour, on good and fairly level roads, should be able to cover 20 miles on a consumption of a United States gallon of gasoline. If it does not do this, the carbureter is incorrectly adjusted or is inefficient.

The causes of an overrich mixture are: faulty carbureter adjustment; leaky float; leaky float valves; float too high on its stem or too heavy; spray nozzle loosened or unscrewed by vibration; improper size jet or choke tube, or both; and dirt on the wire-gauze screen over the mouth of the air-intake pipe. Dirt over a main or auxiliary intake may have gathered gradually or it may have been splashed on from a muddy road, the latter being rather rare in modern cars, in which either a sod pan is fitted or the carbureter is protected by a shield or a web of the crank-case. Its effect is to increase the suction in the spray chamber and to diminish the air taken in.

80. Flooding is a very common source of trouble in two-cycle engines using vaporizers. It is caused by leakage of gasoline into the vaporizer, from which it readily runs into the crank-chamber; the resulting mixture is too rich in gasoline, and, not having sufficient oxygen, is not explosive. When

trouble from flooding is suspected, turn the engine over two or three times, with the gasoline valve and the switch closed. If there is an explosion, note the color of the flame at the relief cock, or priming cup, which should be left open for the purpose. If no explosion occurs, leave the cock or cup open and slowly turn the flywheel to a point just before the exhaust port opens, thus drawing air into the cylinder through the priming cup to dilute what is thought to be an overrich mixture. Now revolve the flywheel in the opposite direction rather rapidly until the spark occurs. If there is no explosion, try again, and repeat the operation two or three times if necessary. If an explosion then takes place, it is evident that flooding is present.

81. To remedy flooding in a two-cycle engine, open the drain cock in the lowest part of the crank-case, and draw off the contents, taking care, however, to replace with a fresh supply the lubricating oil thus drawn out. If there is no draw-off cock, it will be necessary to turn the flywheel many times to exhaust the excess of gasoline in the crank-case, the switch being left closed and the compression relieved as much as possible. After a while, an explosion should take place, then another, gradually becoming more frequent, until finally the engine may run with an explosion at every other revolution or so. The gasoline valve should be kept closed until the charges explode regularly and the red tinge to the flame at the relief cock and smoky exhaust disappear, after which the gasoline may be turned on and regulated at the needle valve in the vaporizer, by closing the valve slightly at first, and, if the engine slows down somewhat, then opening it slightly until it is possible to tell whether it is getting too little or too much gasoline.

82. In case of flooding in a four-cycle engine using a vaporizer, two or three revolutions of the crank-shaft with the throttle closed will usually dispose of any excess of gasoline. Trouble from flooding in a two-cycle engine is the first thing to be suspected when an engine of that type refuses to start readily.

83. If the cause of a failure to start is found to be an insufficient supply of gasoline, due to dirt in the needle valve,

or to a small amount of water in the gasoline piping, lift the valve in the vaporizer from its seat and let a little gasoline run through to clear the obstruction or get a drop or two of the water out, being sure to catch the drip for examination. If there is any water it will show in globular form at the bottom of the vessel. In case water is found, the pipe must be disconnected and drained, and any water in the tank must, if possible, be removed; for a single drop of water will completely close the aperture in the seat of a needle valve.

84. Weak Mixture.—Among the symptoms produced by a weak mixture are insufficient power, although the explosions are regular; a tendency to preignite if there is the slightest carbon deposit; the engine sometimes will miss every other explosion; and there will be back firing into the carbureter. There is likely also to be difficulty in starting the engine. It is not always easy to distinguish between lack of power due to an overrich mixture and that due to a weak mixture, but the tendency of the former is to produce black smoke and of the latter to preignite and miss explosions. Some experimenting with the carbureter adjustment will often be necessary to settle the point.

85. A mixture may be richer at some speeds than at others, and if the carbureter has been readjusted, for example, in the attempt to correct trouble due in reality to a heavy float, the result will be to make the mixture faulty again at certain other speeds. Special causes of weak mixture are dirt or waste in the gasoline pipe or strainer; stale gasoline; carbureter too cold to vaporize; dirt in the spray nozzle; float too light or too low on its stem; and air leaks in the inlet.

Experimenting with the carbureter adjustment should be very cautiously done, with the original setting or adjustment marked so that it can be restored if necessary. The carbureter should then be adjusted slightly in one direction or the other, and the effect noted before further change is made. Very often a combination of adjustments will be necessary, but it is best to make them one at a time. If a radical change is made, it may be very difficult to start the motor at all, and this would

leave the experimenter completely in the dark as to what was required.

86. Effects of Air Leaks.—Air leaks in the inlet pipe leading from the carbureter to the cylinders are manifested most at low engine speeds. If any difficulty is experienced in throttling down, or, in other words, if it is impossible to have the engine run steady with the throttle closed, and the carbureter not set for a rich mixture, it is safe to assume that the mixture is being diluted by air entering the inlet pipe through leaks. The leaks are usually located at the joint between the inlet manifold and the carbureter, or between the manifold and the cylinders, and are usually due to defective gaskets or loose connections. The remedy is to tighten up the bolts of the joint, if these are slack, or to fit new gaskets.

It is rather difficult to locate leaks in the inlet pipe by feeling for the suction by hand, because of the strong current of air constantly set up by the fan. Leaks can generally be located, however, by squirting a liberal supply of cylinder oil around the joints, in which case the oil will be drawn into the mixture or inlet pipe if leaks are present.

87. Air leaks may also be present around the priming cocks where they screw into the cylinder; they may be in the spark plugs themselves, due to defective packing, or around the plugs where they screw into the cylinder. Leaks are very likely to materialize, also, around the plugs over the valve chambers into which the spark plugs are generally screwed. Leaks at any of these points will be clearly evidenced by oil deposits around the leaky parts, and if the leakage is very bad, by a hissing noise, when the engine is turned over. It is evident under these conditions that unless the carbureter is adjusted for an overrich mixture to compensate for the diluting of the mixture by the air leaking in, the engine will run irregularly at low speed, and will run evenly only when the throttle is opened up and its speed increased. The remedy for these leaks is to screw down tight the spark plug, priming cock, etc., as the case may be, having first replaced the old gaskets, where gaskets are used, with new ones.

DIRT IN CARBURETER AND GASOLINE PIPING

88. When the operator is satisfied that there is plenty of fuel in the tank, that the ignition system is in good shape, and that there is clean fuel in the fuel chamber of the carbureter, but the engine runs for a very short time after being started, and then stops, it is good evidence that dirt has become lodged in some vital point in the fuel system. To locate the trouble without undue delay, the different parts of the fuel system should be examined in order. One of the first places to look for dirt is the filter screen of the carbureter, as the fine mesh is very likely to be covered with dirt or lint filtered out of the fuel. If the strainer is found to be in good condition, an examination should be made to see whether or not the fuel is flowing freely through the supply pipe to the carbureter. This is determined by turning off the fuel supply at some point in the line and disconnecting the supply pipe from the carbureter. As soon as the coupling is removed, the fuel should be turned on again and the end of the supply pipe watched to note the way the fuel, if any, issues from it. If the fuel flows freely from the end of the pipe, it is almost certain that the trouble is in the carbureter. If no liquid issues from the end of the pipe, or it drips very slowly, the supply pipe is evidently clogged up, and should be disconnected at the other end and cleaned out. A good method of doing this is to blow out the pipe thoroughly with compressed air. If no compressed air is available, good results are obtained by the use of a tire pump.

An obstructed spray nozzle or jet will sometimes be found the cause of the trouble, as a very small particle of foreign matter will be enough to stop up the small opening. Flooding the carbureter may dislodge the obstruction, but if it does not, it will be necessary to remove the spray nozzle and run a fine wire through it. The compressed air hose can be used to good effect to remove dirt from the carbureter, also.

FLOAT TROUBLES

89. Leaky Float Valve.—When a float valve leaks, the carbureter will drip soon after the main gasoline valve is opened. In this case, the leakage is not stopped by a priming that would remove a small particle of dirt on the float-valve seat. The remedy is to reseal the float valve, which in most carbureters is easily reached by removing a plug directly over it. The float valve can then be turned a few times, back and forth, with a small screwdriver or a pair of pliers, at the same time that it is pressed lightly to its seat. If this does not remedy the trouble, the valve may have to be ground in with flour emery, or some other grinding material. A float valve may leak so little that it gives no trouble while the engine is running, but will flood the carbureter soon after the engine is stopped. The carbureter should then be repaired as quickly as possible, and until this is done, the shut-off cock between the tank and the carbureter should be closed whenever the engine is stopped.

90. Float Too High.—If the float is set too high on its stem it is not lifted by the fuel sufficiently to close the float valve before the fuel escapes from the spray nozzle.

When this trouble is present, the carbureter drips when the main gasoline valve is opened; but the float valve is soon closed by the float if the spray orifice is covered by the finger. The float valve closes tight when manipulated by the fingers, or when the float is lifted by a pair of bent wires. When the trouble is due to a high float, the float will be found in good condition, showing that the trouble is due to its position.

Unless the float is adjustable on its stem, the easiest remedy for this trouble is to bend the levers by which the float acts on the float valve. If this cannot be done, shift the float $\frac{1}{16}$ inch lower on the stem by the use of a soldering iron. In general, the method of remedying the trouble depends on the construction of the carbureter.

91. Float Too Heavy.—The same symptoms are present when the float is too heavy as when the float is too high, but

they are caused generally by a leak in the float or by its being gasoline-soaked.

If the float is hollow, it will sometimes be found that there is present in it a minute leak due generally to some oversight in soldering. If the float is taken out and shaken with the hand, the presence of the gasoline inside of it will at once be apparent. The float should be immersed in warm water until all the gasoline in it is slowly boiled away and its vapor has been expelled through the aperture in the float. By holding the float under water, the escape of bubbles will indicate this aperture. Care should be taken that the vapor escaping from the float does not cause fire. When the leak has been located it should be marked with a pencil, and after the float has become cold the leak may be closed with a minute drop of solder. If the float is of cork, it may be saturated with gasoline. It should be taken out, allowed to dry slowly, and a coat of shellac should be given it, care being taken that the shellac enters all the holes on the surface.

92. Float Too Light or Too Low.—If the float is too light or is adjusted too low, the fuel supply is cut off by the needle valve when the fuel level is still some distance below the orifice of the spray nozzle.

Among the symptoms produced by a light float or a low adjustment are a weak mixture at slow speed, and, probably, difficulty in starting the engine, owing to the fact that considerable suction is required to lift the gasoline to the mouth of the spray nozzle. The height of the gasoline in the spray nozzle can generally be determined, with the aid of an electric flashlight, by a little experimenting with the float, by pushing the latter down for an instant after it has closed the valve.

To remedy the trouble, the float must be weighted slightly, so that the gasoline will rise higher before the float closes its valve. The weight may take the form of a few drops of solder carefully distributed over the float so as not to overbalance it on one side; or, if this is not sufficient, a ring of sheet brass may be soldered to the top of the float.

FUEL TROUBLES

93. Stale Gasoline.—If an engine is left standing for some time unused, more or less of the gasoline in the tank will evaporate, and it may get too stale to give a correct mixture without readjustment of the carbureter. The usual symptoms are difficulty in starting the engine, and insufficient power owing to a weak mixture. One remedy is simply to fill up the tank, when the mixture of old and fresh liquid will probably work satisfactorily; but the best way is to draw off all the stale fuel, and refill the tank with a fresh supply. The stale gasoline can be used for cleaning purposes.

94. Water in Gasoline.—Water may be found in gasoline taken from a barrel standing out of doors. The water, being heavier than the gasoline, will always settle to the bottom, and by close observation it may be seen before it is poured into the tank. If the gasoline is strained through a piece of chamois skin or several layers of cheese cloth, or even through very fine brass-wire gauze, the strainer will hold the water while permitting the gasoline to pass through.

95. The symptom of water in the gasoline will be immediate stoppage of the engine when the water reaches the spray nozzle, in spite of the fact that the ignition system is in perfect order, and the gasoline tank is known not to be empty. The only remedy is to unscrew the drain plug at the bottom of the carbureter, or open the drain cock, and let the water and gasoline run out of the float chamber. Sometimes it may be necessary to drain the sediment chamber of the gasoline strainer, if one is used, and to drain the sediment bowl of the gasoline tank.

96. In stationary practice, besides using gasoline of proper quality, it is of course supposed that the storage tank contains a sufficient quantity of fuel to run the engine. This appears to be a superfluous precaution; nevertheless it has frequently happened that an expert has been sent several hundred miles, on complaint from the purchaser of an engine that he was unable to start it, only to find that there was no gasoline in the

tank. In other cases it was discovered that, instead of gasoline, almost pure water was pumped to the engine. The explanation was that fuel purchased from a local dealer contained a considerable quantity of water, which of course settled to the bottom of the tank, and accumulated gradually until with the tank about one-quarter filled, nothing but water would be delivered to the engine. To avoid this, the contents of the tank should be examined at regular intervals or when the supply is low, and the tank drained whenever there is any doubt about the quality of the liquid that settles in the lower portions.

97. Some mixing valves used in connection with stationary engines are provided with check-valves to prevent the fuel from flowing back to the tank. If dirt or sediment gets into the check-valve, it prevents the valves from seating properly, which allows the fuel to return to the tank. If this difficulty is experienced, the valves should be cleaned out thoroughly.

BACK FIRING AND MUFFLER EXPLOSIONS

98. The cause of back firing through the inlet valve into the carbureter or intake pipe is in most cases due to the delayed combustion of a weak mixture containing an insufficient amount of fuel. The result of such a mixture is a weak explosion and slow burning, so that, during the entire exhaust stroke and even at the beginning of the suction stroke, there is a flame in the combustion chamber. The fresh charge on entering will therefore be ignited by the flame of the delayed combustion of the previous charge; and, as the inlet valve is open at that time toward the air-supply pipe or passage, a loud report will be heard in the air intake. The remedy for this condition is to increase the fuel supply until the explosions become of normal strength and the back firing ceases.

99. Another cause of back firing may be the presence of an incandescent body in the combustion chamber, such as a sharp point or edge of metal, a projecting piece of asbestos packing, soot, or carbonized oil, and similar impurities accumulating in

the cylinder. To stop back firing from these causes, any projections of metal or other material should be removed with a suitable tool, and the walls of the combustion chamber made as smooth as possible, or the cylinder should be cleared of any deposit of soot or carbonized oil that may have gathered there. On account of the shorter time between the opening of the exhaust port and the admission of the new charge in a two-cycle engine, there is much greater liability to back firing in an engine of that type than in a four-cycle engine. In a four-cycle engine back firing will occur only when the inlet valve is off its seat.

100. Explosions in the carbureter are sometimes caused by the inlet valve sticking open and permitting the flame to communicate from the spark. More often it is due to improper mixture, which burns so slowly that flame lingers in the cylinder even after the exhaust stroke is completed and the inlet valve begins to open. Either a weak or a rich mixture will produce this result, though not always both in the same engine.

101. Explosions in the muffler and exhaust piping are usually caused by the ignition of the gas accumulating from missed explosions due to weak mixtures or faulty ignition. They are not usually dangerous unless the muffler is large and is weakened by rusting inside or out. Failure of the ignition to fire all charges admitted to the cylinder, or failure of some of the charges to ignite, because of improper composition of the mixture, will be indicated by heavy reports at the end of the exhaust pipe. One or more charges may in this manner be forced through the cylinder into the exhaust pipe, and the first hot exhaust resulting from the combustion of a charge will fire the mixture that has accumulated in the pipe and the explosion will be accompanied by a loud report.

TROUBLES AND REMEDIES
(PART 2)

FAULTY OPERATION AND ADJUSTMENTS
(Continued)

IGNITION TROUBLES

PREIGNITION

1. Definition.—Premature ignition, or preignition, while somewhat similar to back firing in its nature and origin, manifests itself in a different way and has a different effect on the action of the engine. Premature ignition, as usually understood, is the firing of the partly compressed mixture before the time fixed by the igniting mechanism. Its causes are similar to those that result in back firing, the effect being different in that the charge is ignited later than when back firing takes place, but before the end of the compression stroke. Preignition will cause the engine to lose power because the maximum pressure is exerted on the crank before it reaches the inner dead center, thus having a tendency to turn the crank-shaft in the wrong direction, against the momentum of the flywheels.

2. Causes of Preignition.—Besides the causes cited in connection with back firing, preignition may be due to any one of the following defects: Insufficient cooling of the cylinder, due either to shortage of cooling water or to the fact that portions of the water-jacket become filled with deposits or impurities contained in the water, thus interfering with proper

circulation; compression too high for the grade of fuel used; imperfections in the surfaces of the piston end or valve heads exposed to the combustion, such as sandholes or similar cavities in which a small portion of the burning charge may be confined; electrodes or other parts of the engine exposed to the burning charge too light; or the piston head or exhaust valve insufficiently cooled and becoming red hot while the engine is running under a fairly heavy load.

3. Premature ignition manifests itself by a pounding in the cylinder, and, if permitted to continue, a drop in speed, finally resulting in the stopping of the engine. It will also put an excessive amount of pressure on the bearings, especially the connecting-rod brasses, and cause them to run hot even when properly lubricated. After a shut-down due to premature ignition and a short period during which the engine is idle, which allows the overheated parts to cool off, it is possible to start again without difficulty and run smoothly until the conditions of load again cause a repetition of the trouble.

4. The remedies to be applied, according to the source of the difficulty, are as follows: Increase the water supply until the cooling water leaves the cylinder at a reasonable temperature, which may vary with the fuel used, but which should not be much over 180° F. Clean the water space and ports of any dirt or deposit so as to insure free circulation of the cooling water. Reduce the compression by partly throttling the air and fuel supply. Plug any sandholes or blowholes in the piston or valves, and make these surfaces perfectly smooth. Replace electrodes or other light parts with more substantial ones, capable of absorbing and carrying off the heat without becoming red hot. If necessary, arrange for cooling the piston by blowing air into the open end of the cylinder.

5. Preignition in automobile engines is indicated by early ignition with a retarded spark. Usually, the engine will continue running for several seconds after the switch has been opened. The knock due to preignition has a sharp, metallic ring, easily distinguishable from other knocks in the engine. Even if ignition is not actually started by hot carbon or other

cause, the first increase in pressure after the spark occurs may produce spontaneous ignition of the mixture near the heated object, so that the charge burns from twc or more points at once, thus spreading the flame far more rapidly than usual.

If the engine has two or more cylinders, and only some of them incline to preignition, the result is that it is impossible to time the ignition correctly for all cylinders. The cylinders having a tendency to preignition must receive a late spark to prevent combustion from being completed too early, while the other cylinders will require an early spark. It follows from this that it is impossible to get the engine to develop its full torque, or turning moment, unless it is running so fast that the tendency to preignition may be neglected.

6. As the effect of preignition is to cause combustion to be completed before expansion has begun, it is dangerous to run the engine slowly, and this is true even if only one cylinder is preigniting. If the engine is running at good speed, with an early spark, the symptoms will be those of rapid combustion in the cylinders affected, namely, a hardness in the sound of the explosion, without actual knocking, while in the other cylinders, if any, the explosion will be soft. As the speed of the engine is reduced, and the spark retarded to suit, the hard sound of the explosions gives place to unmistakable knocking. A good test for preignition due to carbon is to start the motor with everything cold, and run the car smartly up the nearest hill before the water in the radiator has had time to get hot. The *bing! bing! bing!* then is a sure sign. If the carbon deposit is very great, the motor may knock when shifting to a higher gear, if this is done quickly with the motor running slowly.

7. Preignition is brought about by incandescent carbon deposits in the combustion chamber, on piston head, or on valves, or by bits of loose carbon left after scraping out, etc. It is sometimes due to small projections on the inner wall of the combustion chamber or head, due to defects in casting. If these are located in the path of the hot gases, it will take very little carbon deposit on them to overheat. It must not be supposed that all carbon deposits are due to neglect. Even the

most scrupulous regulation of the best possible oil, and even the most efficient carbureter, will not wholly prevent a gradual accumulation of carbon. A high-compression engine will, other things being equal, preignite sooner than one with low compression.

BATTERY TROUBLES

8. In stationary gas engines employing dry cells as the sole source of primary current, missing explosions, or failure of the engine to start, are pretty good evidence of the exhaustion of the cells. If the operator feels satisfied that the ignition devices such as spark plugs or igniters, vibrators, etc., are in good order, the condition of the dry cells can be readily determined by connecting an ammeter across the terminals. An ammeter which is commonly used for this purpose, and which may be obtained at a very low price from any automobile supply house, is shown in Fig. 1. In using the instrument, its terminal *a* is placed against the carbon of the dry cell and the terminal *b* of the detachable flexible wire *c* is placed against the zinc terminal of the cell and the reading is quickly taken. The terminals of the dry cell should be short-circuited only for an instant, as, otherwise, the cell will be weakened. A new dry cell should test about 30 amperes at the instant it is tested. Occasionally ammeters are encountered in which the stationary terminal must be connected to the zinc terminal of the dry cell, and the terminal at the end of the flexible wire to the carbon of the dry cell. Hence, if the pointer of the ammeter does not move when connected to the dry cell one way, the connections should be reversed; when no indication is gotten with either method of connection, it shows the cell to be entirely dead. As a general rule a dry cell that shows less than 10 amperes is worthless for ignition work.

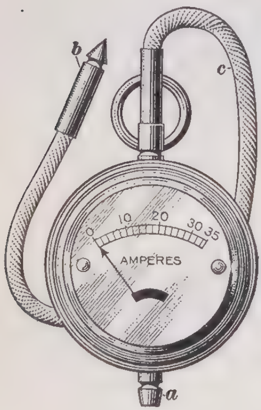


FIG. 1

9. In testing a dry-cell battery it is well to remember that a single bad cell will seriously affect the whole battery, and hence if a bad cell (that is, one showing a very low amperage) is found, it should at once be replaced.

The fact that a newly bought set of dry cells has just been installed is not a guarantee that the battery is of sufficient strength; for various reasons newly bought dry cells may be worthless for ignition purposes. Hence, in purchasing dry cells, it is a good policy to patronize a reliable house, or a place where the stock is renewed frequently, thus lessening the likelihood of obtaining old cells.

10. In testing dry cells, the terminals of both the ammeter and the cells must be clean so as to make a good electrical connection with each other, otherwise the reading of the ammeter is apt to be misleading. Each cell should be tested separately, and the ammeter should be connected across the terminals only for an instant, or the battery will rapidly lose its strength.

11. The terminals of a battery should always be kept clean and bright. Dirt, if allowed to accumulate around and between the terminals, especially if moist, may allow the current to pass slowly through it, thus discharging the battery. Individual dry cells are enclosed in pasteboard coverings to prevent them from being short-circuited when grouped in a case without further insulation. If this pasteboard becomes wet, it allows leakage of current when the cells are brought in contact with each other. If they must be used in this condition, they should be set well apart, so that there will be no danger of their touching each other, and must not touch a metallic part that would serve as a metallic connection between them. If they cannot well be separated, they should be properly insulated by pieces of glass, rubber, porcelain, or other insulating material.

12. The cells should be held tightly in place, as shaking about tends to loosen the connections. The terminal nuts work loose very easily when exposed to vibration, and should be tightened hard against the wire under them, by use of a

pair of pliers if necessary. If the nut is loose on the thread, it can be tightened by damaging the thread slightly. This practice is not recommended for any other point in the ignition system, however. No tools or other metal objects should be carelessly allowed to lie on top of an open box containing dry cells. If the metal makes contact with any of the terminals, a direct short circuit will result, and the cells will rapidly lose their strength.

13. If a wet battery becomes exhausted through long service or accidental short circuit in its parts or connections, the contents of the jars must be emptied and the charge renewed. The manufacturer or dealer in electrical supplies furnishes full printed instructions with every set of renewals for batteries. It is generally false economy to try to use part of the old charge. In almost every case it is far better to throw away all of the original zincs, oxide plates, and solution, rather than to try to rejuvenate the cell by adding to or replacing part of its contents. The wet battery can be tested in the same manner as a dry battery. As the internal resistance of a wet cell is greater than that of a dry one, the current passing through the ammeter connected across the terminals of a wet cell will give a lower reading than when connected across the terminals of a dry cell.

STORAGE-BATTERY TROUBLES

14. If, upon examination, it is found that the electrolyte level in one cell rapidly lowers and that electrolyte can be seen at the bottom and outside the cell, a cracked jar is indicated. These jars, in automobile batteries, are made of hard rubber and cannot be readily repaired. The only remedy is a new jar, applied at a battery-service station, because frequently new plates and separators will be also required.

15. If electrolyte has been spilled from a cell or cells through an accident, the cells must be refilled at once to the proper level with new electrolyte and the battery recharged. Electrolyte of the proper strength can be made by adding two

volumes of chemically pure sulphuric acid to five volumes of distilled water. Neither the ordinary commercial sulphuric acid nor natural water is suitable for electrolyte. Chemically pure sulphuric acid has a specific gravity of 1.840.

For mixing the electrolyte a thoroughly clean earthenware or glass vessel must be used. The water is placed in the vessel first and then the acid is added very slowly. Great heat is developed in making the mixture, and the electrolyte must be allowed to cool before it is transferred to a battery. It is very dangerous to attempt to make electrolyte by adding the water to the acid.

16. If, upon making a hydrometer test, it is found that one cell of a storage battery has a much lower specific gravity, that is, state of charge, than the others, and it is known that this is not due to the excessive adding of water, an internal short circuit in that cell is indicated. This short circuit may be the effect of plates having buckled badly, or it may be from some other cause. The defective cell, or the whole storage battery, should be sent to a battery-repair station for repair.

17. Modern storage batteries for starting or lighting work are made with deep sediment spaces below the plates, and consequently if the batteries have not been abused will not require to have the sediment removed for several years. If sediment has collected so as to touch the plates, the necessity of cleaning it out is indicated by lack of capacity of the storage battery, excessive heating of the battery while it is being charged, and excessive evaporation of the electrolyte. The cleaning out should be entrusted to a battery-service station.

18. The contacts between cable terminals and the storage-battery binding posts must be good, and the clamping nuts must be set up tight. Poor contacts will manifest themselves by great heating of the terminals, plainly discoverable with the hand after the battery has been charging for 10 minutes or so. When the cable terminals are attached to the binding posts, they should be clean and bright, and should be lightly coated all over with vaseline before assembling them; the nuts should then be set up tight. All brass that is exposed should be

covered thickly with vaseline. If the terminals and binding posts are covered with verdigris, this can be removed by means of a strong solution of washing soda and water; great care must be taken not to spill any of this solution into the electrolyte. Poor contacts between terminals and binding posts prevent a proper charging of the storage battery.

19. If any electrolyte has been spilled into the battery box, this electrolyte should be mopped up at once with waste saturated with ammonia. The ammonia neutralizes, and hence renders harmless, the sulphuric acid in the electrolyte. The box and battery jars should be wiped dry before assembling, and if the electrolyte was spilled out from the storage battery itself, fresh electrolyte should be added until the plates are covered to the correct depth. Great care must be exercised not to let ammonia enter the cells of the storage battery.

20. In many storage batteries the different cells are connected together by bolted connections. It is very essential that these connections make good contact and be coated with vaseline before assembling, to prevent corrosion; poor contacts are easily discovered by their heating when the battery is charging. If one cell has been removed from the storage battery, on replacing it great care must be exercised to connect it properly to the other cells; the positive terminal of one cell always connects to the negative terminal of an adjoining cell of the group of cells. As a general rule, the cell terminals are plainly marked, the positive terminal being indicated either by painting it red, or by a large plus sign, or by being lettered POS.

21. As hydrogen gas, which is highly inflammable, is given off by the electrolyte when the battery is nearly charged, a naked flame must not be brought near the battery while it is gassing.

If a storage battery has been recharged until the specific gravity of the electrolyte does not rise any more and after standing idle a few hours is found by a hydrometer test to be partly or wholly discharged again, the battery is said not to

holds its charge. In the process of discharging a storage battery, sulphate of lead is formed in the active material of the plates. Under normal, fairly low discharge rates, this sulphate of lead is in a very finely divided state and is then readily decomposed by the electric current upon charging, the active material of the positive plate being oxidized to lead peroxide and that of the negative plate being reduced to spongy lead. Now, if a storage battery is discharged very low and allowed to stand for some time in a discharged condition, the sulphate-of-lead particles coalesce into larger masses that are hard and crystalline and are difficult to decompose. A storage battery in this condition is said to be *sulphated,* and if it is otherwise in good condition may sometimes be restored by charging it for a long time at a very low charging rate, say about one-quarter the normal charging rate. It may take one week, or even two, of continual charging to bring the battery back to a good condition. It will be understood that the charging of the battery is to be done with current from an outside source.

When the plates have become sulphated from neglect to keep them covered with electrolyte, the battery is usually ruined and must be sent to a properly equipped battery-repair station for repair. Such repair stations are maintained by battery makers in most of the larger cities; private battery-repair shops are also found in many cities.

22. A fully charged storage battery should test between 1.280 and 1.300 by the hydrometer. The battery is considered to be discharged when the reading is 1.160. If, upon charging a storage battery in which the electrolyte showed a specific gravity below 1.100 it is noted after 4 or 5 hours charging that the specific gravity of the electrolyte does not rise, it is a good indication of too much water having been added to the electrolyte in the cells. In batteries thus abused it is sometimes found that one or more cells will charge properly while others will not. The remedy is to replace the electrolyte of all cells that do not charge, with fresh electrolyte having a specific gravity of approximately 1.28. Then the battery should be charged at its regular charging rate until it is fully charged.

If, on the completion of the charge, a cell or cells into which no new electrolyte was put show a much lower specific gravity than those that were supplied with new electrolyte, some of the old electrolyte should be removed from the cell with a syringe, replaced with fresh electrolyte, and the battery charged again.

The use of impure water, or the addition of sulphuric acid to the electrolyte will ultimately result in a battery that cannot be charged. In that case the battery is practically ruined and must be sent to a battery-repair station. The actual repairing of a storage battery is a special line of business entirely outside the scope of garage work, requiring special knowledge and special appliances, and for these reasons should only be entrusted to shops specializing on this work.

By writing to the car maker or battery maker the address of the nearest battery-service station can be obtained.

SPARK-PLUG DISORDERS

23. Broken Spark-Plug Porcelain.—The breaking of a spark-plug porcelain usually results in complete failure to ignite the charge in that particular cylinder, owing to the short-circuiting of the secondary current through the break. The outer end of the porcelain will generally be loose when tried by the fingers. The only remedy is to buy a new porcelain or a new plug.

The usual cause of breaking is screwing the bushing down too tight, or striking the porcelain with a wrench. If the asbestos packing is of uneven thickness, it may be necessary to screw the bushing quite tight to prevent leakage. Splashing of water on a hot porcelain will also cause breaking. Remedies for such trouble are found in using new asbestos packing and in providing protection from water, etc.

24. Soot on Spark-Plug Porcelain.—Soot on the part of the spark plug inside of the cylinder will quickly stop sparking at the points of the plug, because the high-tension current will be short-circuited. If the engine has only one cylinder, it

is a simple matter to remove the plug and examine it. If the engine is of the multiple-cylinder type, it is more difficult to locate the bad plug or plugs in case all of the cylinders are not affected. With such engines, it is necessary first to locate the cylinder or cylinders that are not firing, to avoid the removal of all of the spark plugs. The quickest method of doing this is to short-circuit the spark plug in each cylinder in turn and note the effect it has on the running of the engine. To do this, use a hammer, screwdriver, or other metal body with a wooden handle, and, with the engine running idle, touch the metal to some metal part of the engine, grasping the tool by the wooden handle. Then bring the metal of the tool in contact with the terminal of the spark plug. This makes the plug of that cylinder inoperative, and if the ignition had been taking place properly in the cylinder being tested, the short-circuiting of the spark plug will slow the engine down perceptibly. If there was no ignition taking place, the short-circuiting of the spark plug makes no difference in the running of the engine. The handle of the screwdriver or hammer must be wiped clean and dry to prevent the operator from receiving a disagreeable shock.

25. The cylinder that misses fire having been located, the trouble may be due to the spark plug or to the secondary wire carrying the current to the spark plug having become detached or broken. Inspection of the wire will reveal its condition. If the spark-plug core is found thickly covered with carbon, the plug needs cleaning; if it seems to be in good order it may be tested by laying it on the cylinder so that its shell touches the metal of the cylinder. The secondary wire being attached to the spark plug, the engine is started; if no spark passes at the spark-plug gap, the spark plug is bad. However, the fact that a spark does pass is not conclusive evidence that the spark plug is in good condition, as a spark plug may spark freely in the open air and yet fail utterly to do so under the pressure existing in the combustion chamber near the end of the compression stroke. If the substitution of a new plug induces regular firing in a cylinder that previously misfired, it shows

the removed spark plug to be bad, even though it sparks when tested. The remedy is to take the plug apart to examine the core for cracks, to clean it thoroughly, and to adjust the spark gap to the correct amount. The makers of practically all ignition systems furnish a gauge showing the correct spark gap to be used with their system; with magnetos this gauge will usually be found attached to the wrench furnished for adjusting the circuit-breaker.

26. The causes of sooting are too much lubricating oil, inferior oil, or an overrich mixture. The overrich mixture will deposit pure black soot, whereas an excessive quantity of lubricating oil will produce a rusty-brown deposit. Inferior oil may produce almost any sort of deposit, according to its quality. A great excess of either good or bad oil will not burn completely before it reaches the plug, and will deposit on the latter a greasy mixture of carbon, tar, and oil. An engine receiving oil in such quantities as this will foul the plugs in a short time, and energetic measures must be taken to get rid of the surplus oil.

27. A spark plug that sparks perfectly when removed from the cylinder and is otherwise good may fail to ignite the charge when in place, because the spark points are located too far apart. Generally speaking, the distance between the spark points should not be less than $\frac{1}{64}$ inch nor more than $\frac{1}{32}$ inch. Spark gaps gradually become wider while the plugs are in use, through the burning away of the electrodes. If the spark points are too far apart they can be brought closer, in many designs of spark plugs, by bending one or both with a pair of pliers.

The indication that the spark points are too far apart, with a magneto ignition system, in which the spark intensity depends on the magneto armature speed, is that the engine will fire evenly at high speeds but irregularly at low speeds; in fact, may refuse to run at all on the magneto ignition when slowed down to its regular idling speed. With dynamo-and-storage-battery, and also with battery, ignition systems in which the spark intensity does not depend on the engine speed, evidence

that one or more spark plugs have their points too far apart is given by the engine running irregularly at all speeds.

28. Leaky Spark Plug.—A leak between the spark-plug shell and the cylinder will be denoted by the hiss of escaping gas on the compression and power strokes. The plug may be screwed tighter or a new gasket used. If the leak is through or past the packing inside the plug, the same hiss will be heard, and in addition the outer end of the porcelain will show traces of soot after the gases have been leaking for some time. If the bushing of the plug has been screwed as tight as is prudent, with regard to the safety of the porcelain, it will be necessary to repack the plug. A plug allowed to leak to any noticeable extent will overheat, cracking the porcelain or burning the screw threads.

MAKE-AND-BREAK IGNITER TROUBLES

29. Poor Contacts.—In order to obtain a spark of sufficient size in the combustion chambers of engines equipped with the make-and-break system of ignition, it is necessary that a good contact be made between the two electrodes of the igniter plug before they separate. The current passes through the bearing of the movable electrode, and, if the contact between the bearing and the stem of the electrode is poor, only a weak curent can find its way to the point of contact, resulting in a feeble spark that may be too weak to fire the compressed mixture. Poor contact of the electrode may be caused by an inferior quality of lubricating oil forming a thin layer of carbon on the stem, or it may be due to wear of the bearing and a loose fit of the stem. To prevent wear on the stem and bearing it is important that the seat of the electrode be kept tight, so as to prevent the heat of the burning charge from reaching the stem and to keep it as cool as possible. This will aid in keeping the stem well lubricated, as the oil cannot be burned and form the objectionable carbon deposit. At the same time, the electrode will move easily without sticking, which is essential to a prompt separation of the two contact points.

30. Short Circuits.—A ground or short circuit of the current is often responsible for difficulties or failures of the igniter. This may be caused by carbonized oil on the exposed surface of the insulators, or by dampness between the mica washers if these are used for insulation. By placing the igniter plug in a warm place and drying it thoroughly, a short circuit of this kind can often be remedied.

31. Short-Time Contact.—The length of time during which the electrode points are in contact has a decided effect on the size of the spark. To test whether the contact is of sufficient duration, hold the two points together by exerting pressure by hand on the movable electrode. If this is found to cure the trouble, it is a sure indication that the contact is too short, and the parts that make the contact must then be adjusted so as to prolong the time of contact. This is accomplished in some igniters by increasing the tension of the igniter contact spring, while in others the adjustment is made by changing the relative positions of the interrupter lever of the movable electrode and the blade of the igniter lever that operates it and presses it against the fixed electrode.

32. Dirty Contact Points.—The contact points must be kept free from rust or moisture, both of which will interfere with the making of a bright spark. An occasional cleaning of the points by the use of emery cloth is advisable. Moisture on the electrode may be caused by condensation of the exhaust gases if the electrodes are very cold, which is likely to be the case in freezing weather before starting. The remedy is to heat the igniter plug thoroughly before attempting to start the engine.

COIL DERANGEMENTS

33. Vibrator Out of Adjustment.—If the vibrator on an induction coil is out of adjustment, it will be evidenced by an erratic running of the engine. In addition to its effect on the engine, the adjustment of the vibrator has considerable influence on the current consumption of the coil. Too tight an adjustment will cause the engine to run weakly and unevenly.

When dry cells are used as a source of current, too tight an adjustment of the contact points will cause a rapid exhaustion of the cells. Too light a pressure of the contact screw will have the same effect on the running of the engine as too tight an adjustment. When the engine has two or more cylinders provided with individual coils, it is important that all of the vibrators be adjusted alike. A tightly adjusted vibrator will fire the charge earlier than a lightly adjusted one, and thus an engine will fail to develop its full power unless the adjustment is the same on each coil.

34. Dirty or Pitted Contact Points.—If the contact points of the coil are dirty or pitted, so that they do not make good contact, the result will be irregular ignition, sometimes followed by complete stopping of ignition. A contact point is said to be pitted when it has small depressions, or pits, burned into it. The pitting may be the natural result of the current passing between the points, or it may be caused by a badly set contact, a too tightly adjusted vibrator, or too high a voltage in the primary circuit, as, for instance, when too many dry cells are used in the battery. Too high a voltage in the primary circuit is indicated by excessive sparking at the contact points. Unless the number is known to be correct for the particular coil at hand, one or two of the cells should be cut out. If reducing the number of cells does not stop the excessive sparking, then the trouble is located elsewhere in the system, probably in the condenser, or in the insulation of the coil.

Contact points sometimes burn or fuse together. This is liable to result when there is excessive sparking at the points, or when the points are not adjusted properly. When sticking of the points occurs, press down the vibrator a few times, and when they separate, true the points up properly before the coil is placed in service again.

A very thin, fine file, which is made expressly for this purpose and which may be obtained at little cost at any automobile supply station, should be used for trimming the surfaces of contact points in induction coils. The contacts should be filed until good surfaces are obtained, and the stationary and mov-

able contacts have a full bearing over their full contact surface. If the surfaces are merely blackened, it is sufficient to double a strip of very fine emery cloth, insert the cloth between the points, press them tight against the cloth, and pull the cloth through them a few times. The contacts should then be adjusted until a high, clear, and loud sound is given out by the vibrator, and the same sound is given out by all vibrators used in the system.

35. Defective Condenser.—A condenser short-circuited or having one of the connections broken will be indicated by sparking at the trembler and timer contacts, and by rapid burning of the metal where the spark occurs. The only remedy is to send the coil to the factory for repairs.

36. Short-Circuited Coil.—A spark coil may short-circuit from breakdown of the insulation in either the primary or the secondary winding. The symptoms are a poor spark or none at all, and refusal of the vibrator to work, even with a good battery. The only remedy is to send the coil to the factory for repairs. The spark coil must be kept in a thoroughly dry place, as moisture will surely cause trouble and will interfere with the passing of the current through the coil to the engine. If the spark coil is found to be moist, it can generally be put in serviceable condition by drying it in an oven.

WIRING TROUBLES

37. Break in the Primary Circuit.—The symptoms produced by a break in the primary circuit depend on the ignition system and where the break occurred. Thus, in ignition systems using individual induction coils, where a primary wire runs from each timer terminal to each coil, the breaking of one of these primary wires will produce misfiring in only one cylinder. On the other hand, if the primary wire from the battery, dynamo, or magneto to the coils should break, the ignition will be cut off from all cylinders.

In all high-tension, magneto ignition systems in which the magneto ignition is cut off by short-circuiting the primary cir-

cuit to the ground, the breaking of the primary grounding wire running from the magneto to the ignition switch, or the grounding wire between the switch and the ground, prevents ignition from being cut off; that is, the engine will run with the ignition switch placed in its "Off" position.

In ignition systems in which the ignition switch is connected by a wire to a ground, and this ground connection broken by placing the switch handle in the "Off" position, the breaking of the switch grounding wire will prevent ignition in all cylinders. The breaking of a primary wire between the battery and switch, or battery and ground, will stop ignition to all cylinders.

In some cases of battery ignition by individual induction coils, the rotor of the timer is grounded not only through its bearings, but also by a special brush bearing on the rotor and connected by a grounding wire to the ground; breaking of this grounding wire may or may not interfere with the ignition of all cylinders, depending on how well the rotor makes electric contact to the ground through its bearings.

38. A wire that has become disconnected from a terminal, or binding post, produces the same symptoms as a broken wire. Very erratic action of the ignition system can be produced by loose connections between wires and their terminals, or by breaks in wires where electric connection may be intermittently restored by vibration. The usual cause of breaks in the primary circuit is vibration, which will also loosen nuts on binding posts.

The first step in locating these breaks is to test every binding post, by shaking the wires with the fingers and testing the tightness of the binding nut. If this does not disclose the trouble, a break in the wiring is looked for. It will generally be found close to a binding post, switch terminal, or other connection, where the bending due to vibration is most severe. If the wire has a soldered joint, it may be brittle at that joint and may have broken; or, it may have been fastened in such a manner as to strain it; or a badly made and twisted joint may have worked loose.

Where wires are not provided with proper terminals, breaks may be looked for at the place where the insulation is stripped off. All terminals at the ends of primary wires should have ears that encircle the insulation; terminals that are fastened only to the strands of copper and are not supported by the insulation should not be used, as they soon will give trouble.

39. When no break in any primary wire can be detected by an inspection, such as that just described, it may be tested for electrically. The only apparatus required for this are two dry cells and an ordinary electric door bell as used in dwelling houses, or a buzzer. The two dry cells are connected in series and the free terminal of one cell is connected to the one binding post of the door bell. The wire to be tested is then removed and its one terminal connected to the free terminal of the second cell. If the bell rings on touching the second binding post of the door bell with the free end of the wire being tested, the wire is probably not broken; if the bell does not ring, the wire undergoing test is broken.

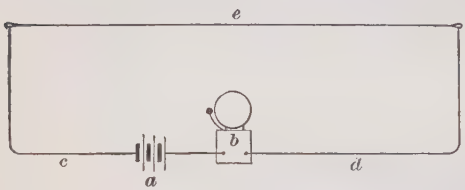


FIG. 2

A wire may be broken inside the insulation and the broken ends may be held together by the insulation so that the wire will pass the test just given, and yet fail as soon as put in service, vibration then separating the broken ends. For this reason the test illustrated in diagrammatic form in Fig. 2 is preferable. In this figure a dry-cell battery *a* is connected in series to an electric bell *b*, and separate test wires *c* and *d* are used, the one being attached to the free terminal of the battery and the other to the free binding post of the bell. The wire *e* that is to be tested is stretched out on a table, board, or on the floor under some tension, and the ends of the test wires *c* and *d* are applied to the terminals of the wire *e*. If the bell rings, it shows that the electric circuit is complete; in other words, the wire being tested is not broken.

The method of testing just explained can be applied to wires in place, but does not positively prove the wire to be unbroken unless it is put under tension from end to end while being tested.

40. Short Circuit or Ground in Primary.—A short circuit, or ground, in a primary wire, by which is meant that a primary wire has become bared by rubbing against metal and hence makes electric contact with the metal work of the car or engine, as the case may be, will cause ignition trouble in all ignition systems using a grounded primary circuit. Some ignition systems are now in use in which the primary ignition circuit is not grounded, but where two wires are used, the one wire conveys current from a dynamo, storage battery, or dry-cell battery through a switch and induction coil to a timer-distributor, and the other wire returns the current to its source. In a system in which the primary circuit is not grounded, no ignition trouble will be experienced if one of the primary wires should become bared and be in contact with the metal of the car; both conductors must be grounded simultaneously to interfere with the ignition. However, should a bare spot be discovered on a wire of an ungrounded primary-circuit ignition system, through chafing of the wire, the bare spot should be covered at once with one of the plastic rubber preparations used for mending cuts in tires and well wrapped with electrician's tape; the cause of the chafing should then be removed. The same thing should be done to an injured wire of a grounded system.

41. A grounded primary conductor is usually easily discovered by inspecting each primary wire throughout its whole length, looking for a spot where the insulation has been chafed off against metal of the car. The trouble that a grounded primary wire may cause in an ignition system using a grounded primary circuit depends on the character of the ground and the purpose of the primary conductor accidentally grounded. Thus, in an ignition system using individual coils, the grounding of a primary wire between the timer and coils will affect only one cylinder, but if a single coil is used the grounding of a primary

wire affects all cylinders. In high-tension magneto ignition systems in which the ignition is cut off by grounding the primary circuit, an accidental ground of the grounding wire from the switch to the ground has no effect on the ignition; on the other hand, if the primary wire from the magneto armature to the ignition switch should become grounded, the ignition will be entirely cut off while this ground exists.

42. As the secondary wiring is quite large and strong, very little trouble is experienced in practice from broken or grounded secondary cables unless the wiring is poorly supported. A broken or grounded secondary wire between a distributor or induction coil and a spark plug will affect only the one spark plug; a broken or grounded secondary wire between a distributor and an induction coil, and also a broken grounding wire from an induction coil, will cut off the ignition from all cylinders.

The break or ground in a secondary wire is usually found easily by inspection. A repair of a broken wire can be effected by twisting the broken ends of the copper strands together and taping the joint, but at the first opportunity a new wire should be fitted. Except in an emergency, primary wire should not be used for high-tension wiring, because the insulation of primary wire cannot withstand for any length of time the high voltage of the current passing through the secondary wiring of the ignition system. A grounded secondary wire can be temporarily repaired in the same manner as a grounded primary.

43. Loose Electrical Connections.—To obviate failure to start because of loose or defective electrical connections, the ignition mechanism should be tested carefully. With the make-and-break system of ignition this is done by disconnecting the wire from the binding post or nut of the insulated electrode while the electrodes are in contact, and then snapping the end of the wire across the binding nut of the insulated electrode. If a good fat spark is produced when the wire slips off the nut, thus breaking the circuit, it is evident that the circuit is not defective beyond the igniter and that the contact between the electrodes is good.

44. If, with the wire connected to the insulated electrode and with the igniter contact points separated, a screwdriver were placed so as to make contact with the binding nut of the insulated electrode and with a capscrew, studbolt, or some bright part of the engine, the production of a spark when the contact between the screwdriver and the nut of the insulated electrode is broken would indicate that no short circuit exists in the igniter. If, however, no spark should be produced on breaking contact with the screwdriver, it would indicate the existence of a short circuit that should be found and eliminated. Should a spark be produced on breaking contact with the screwdriver when the two electrodes are in contact, it would be evidence of poor contact between the points. No spark will appear on breaking the circuit when the contact between the points is good.

45. The break of a wire inside the insulation, while not of frequent occurrence, is harder to locate than a loose electrical connection. In cases where it appears impossible to find the trouble, the existence of the broken wire may be determined by running a temporary wire from the coil to the engine, spark coil, switch, or battery, as the broken wire may be so situated as to show occasionally either an open or a closed circuit.

A loose rocker-arm fastened to the movable electrode will sometimes give considerable trouble that will be found difficult to locate. A very little lost motion where the shaft is small is increased rapidly; and, as soon as the shaft becomes the least bit loose, the pounding to which it is subjected will cause it to loosen very quickly.

TIMER TROUBLES

46. Timer Contacts Roughened by Sparking. Trouble due to roughening of the timer contacts by sparking is likely to occur in any timer in which the contact segments are inserted flush with the insulated barrel or internal ring, instead of projecting therefrom.

The symptom produced by roughened contacts is irregular firing, due to jumping of the contact roller or fingers. This is not noticeable at low speeds, but becomes marked as the speed increases. The remedy is to true the insulator ring and segments in a machine shop, and, if necessary, put in a new roller or contact fingers.

47. Wabbling Timer.—Some timers have their stationary portion supported on the shaft by a very short bearing that quickly wears loose and allows the stationary portion to wabble out of its correct plane. This will cause irregular firing or even misfiring. One may easily determine whether the cause of the misfiring is here or elsewhere by steadying the timer with the hand. The remedy is to bush the bearing and, if possible, to make it longer.

If the timer has been worn to such a state that it cannot readily be put in good condition again, it is well to purchase a new one from the maker. The cost of a new timer is not great compared to the annoyance caused by a defective one, and it pays to invest in a new one of the latest type. In case the timer is found to be in good condition, it should be cleaned out thoroughly with gasoline, and the setscrews holding the rotating members to the shaft, if any are used, tightened securely. The springs should have sufficient tension to insure a good contact between the rotating and stationary members, and if the contacts are much burned, they must be smoothed with a fine file. If the timer is intended to be filled with grease, it should be packed with clean grease of a good quality. The wires which are connected to the timer case should make firm connections in their binding posts, and an examination should be made to see if any of the wires are broken at this point. Owing to the fact that they are constantly being bent by the rotation of the timer, the timer wires are quite likely to give trouble.

48. The timing apparatus of timer-distributors used with ignition systems employing a single induction coil, of either the vibrating or non-vibrating type, contains little mechanism to get out of order. Dirty or burned contacts in the timer will manifest themselves by erratic firing; the remedy is to file or

grind the contacts clean and bright and readjust them. The movable contact arm operated by the cam of the rotor shaft may stick from lack of lubrication; or the spring that draws the movable contact arm away from the stationary contact screw may break; in either case the remedy is obvious. Trouble may be experienced from improper adjustment of the contact screw, which may produce erratic firing, or when badly out of adjustment may entirely prevent ignition through failure to close the primary circuit.

Unlike timers of the roller type, timer-distributors cannot be run in oil or be packed with grease; they depend for their successful operation on being kept scrupulously clean. Thus, a single grain of dust getting between the contacts prevents the closing of the primary circuit. The only parts requiring lubrication occasionally will be the pin on which the movable contact arm swings; a single drop of oil should be sufficient for a year. As much grease as can be picked up with the end of a toothpick may be applied to the lobes of the cam perhaps once every month or two.

49. The distance that the contact points of circuit-breakers should separate has been determined by the maker of the ignition system, who usually either gives this measurement or furnishes a flat steel gauge of the correct thickness by which the setting of the contacts can be tested and the necessary adjustment made. It is very essential that this adjustment be made right, as in some circuit-breakers even a slight variation may produce a considerable difference in the time, in reference to the position of the piston in the cylinder, at which the spark occurs. In all magnetos, increasing the distance the contact points separate causes the spark to occur earlier in the piston stroke, and lessening the distance causes the spark to occur later. Furthermore, the contact screw may be screwed in or out so far that in the one case no contact is made, or in the other case the contacts cannot separate. For these reasons the contacts should always be adjusted to suit the gauge or dimension furnished. This statement also applies to the circuit-breakers of timer-distributors.

It is inadvisable to make any adjustment of circuit-breaker contacts, either in timer-distributors or in magnetos, without first examining the contacts and if necessary smoothing them properly with a fine file. It will often be found that the one contact has burned away in the center so that its contact surface has become concave, and that the corresponding surface of the other contact has become convex. If the contacts are adjusted to suit the gauge while in this condition they will separate entirely too far.

The final filing of contacts should be done with a so-called *dead smooth flat file;* if contacts are made of tungsten, they will be so hard that a file will not touch them and hence they must be ground smooth and true.

50. Incorrect Timing.—With engines having make-and-break ignition mechanism, even if the current is sufficient and there are no leaks, the time of contact may be too short, may be made at the wrong point in the stroke, or may be broken when it should not be, owing to incorrect timing. The timing may be tested by turning the flywheel carefully in the proper direction, and noting when the contact is made and at what point the spark occurs. By scratching the flywheel at these points, when the engine is running satisfactorily, it is always a simple matter to correct any trouble in the time of sparking. Changing the time of ignition without following any particular rule or without knowledge of what one is doing is very bad practice, and is more likely to aggravate than to remedy the difficulty. It is evident that, in multicylinder engines, it is quite important that there should be for each cylinder the same relative time of making and breaking the contact, with the same length of time in contact.

MISCELLANEOUS TROUBLES

51. Clogged Muffler.—Habitual feeding of an excess of lubricating oil to the engine will gradually clog the muffler with a mixture of carbon and half-burned oil, which will reduce the power of the engine and be very difficult to remove. The symptoms produced are loss of power and inability to

speed up the engine when the mixture, compression, valve timing, and ignition are known to be good; if the exhaust pipes can be disconnected, the engine gives its full power at once. To remedy the trouble, take off the muffler and saturate the interior with kerosene, after which the deposit can usually be knocked, scraped, or shaken out.

52. Gasoline Leaks.—Leaks in the gasoline tank or piping are more likely to occur at unions than anywhere else, and all joints and fittings should be soldered or brazed, as well as screwed, as the piping is then not liable to be broken at the threads, reinforced as they are with solder. Unions should be very heavy, and should be examined for leaks carefully and often. Do not use a light or match, but rub the finger around the joint, when, if there is a leak, it may be detected by the odor that will remain on the finger. Small leaks may be stopped temporarily by means of cloth and shellac or soap. Insulating tape will be found useless for the purpose, as the gasoline is a solvent for the insulating material.

A good cord closely and tightly wound will be found serviceable. Shellac and cloth bound on tightly and allowed to dry with no gasoline in the pipe will be found very effective in stopping leaks. It is necessary to be extremely careful of fire in the presence or suspected presence of gasoline, particularly when in the form of vapor and mixed with air.

53. Water in Exhaust Pipe or Muffler.—The exhaust gases from stationary gas or gasoline engines contain a certain amount of moisture, part of which is condensed and deposited in the exhaust pipe or muffler, where it may become a source of trouble if no provision has been made to drain these connections properly or if the draining devices accidentally fail to perform their functions as expected. Especially during cold weather, when the condensation in the exhaust connections is greater than at more moderate temperatures, it is advisable to inspect closely the condition of the drain cocks. If neglected, the level of the water in the muffler may rise so far as to prevent the exhaust gas from being expelled, causing loss of power and finally stopping of the engine.

54. In engines in which the governor acts on the exhaust valve, and this valve is kept open while running under light load, the trouble from water in the exhaust, when no charges are admitted to the cylinder, is naturally intensified, on account of the fact that a portion of this water is drawn into the cylinder while the valve is open during the suction stroke. The presence of water in the exhaust connections is usually indicated by steam or water spray issuing from the end of the exhaust pipe.

As before stated, water is frequently used for deadening the noise of the exhaust by introducing it in a small steady stream into the exhaust pipe and allowing it to be carried off in the shape of vapor or spray with the exhaust gases. In such cases, the draining devices require particular attention, because, in the case of failure to have a free outlet to the drain for any part of the water not carried off with the exhaust, the accumulation of water would in a short time be sufficient to stop the engine.

55. Failure to Govern.—If, in an engine governed by throttling, as in the case of some stationary gas engines and some trucks, the connection between the governor and the throttle is too long, the throttle may fail to close until the governor weights have been moved out to an excessive extent by the speed of the engine. In an old engine, wear of the connecting links may produce the same result. Sometimes there is an adjustable screw and nut connection between the governor and the throttle, and this is easily adjusted. Sometimes, however, it may be necessary to bend the rod connecting the two. The throttle should be opened, and its position when barely open should be marked in such a way that it will be known when the throttle is reassembled. Then the engine should be run idle and the position of the governor lever noted when the engine is running at the speed at which it is desired that the governor should act. With these particulars known, it is easy to shorten the rod to bring the throttle to the desired position. It should be remembered that a very slight opening of the throttle is sufficient to keep the motor running.

56. In the engine governed by the hit-or-miss system it is very common to find the inlet valve opened by the action of a knife-edge blade that is swung in and out under control of the governor. The governor itself, which is of the centrifugal fly-ball type, may be driven by belt, chain, or gears from the crank-shaft. If it is driven by belt and the belt is allowed to become too slack, through stretching or wear, there will be excessive slipping, and the governor will not be driven at the proper speed in relation to the speed of the engine. The result will be irregular running. The irregularity will be increased if the governor parts are allowed to become fouled with oil, grease, and dirt. In many engines, particularly those of the small stationary and portable types, the lubricant used on the governor will grow gummy, and, when mixed with dust, will cause the governor to be sluggish, or slow to respond to speed changes. This trouble will be greater in cold weather, owing to the effect of the cold on the lubricant. As a consequence, a considerable increase of speed of the engine will be required before the governor balls will move so as to cut out explosions, and the speed will then fall considerably before the ignition of charges is resumed. This alternate slowing and speeding of the engine is called **racing,** and may be traced to faulty governing.

57. If irregular running is caused by a dirty and clogged governor, the governor parts should be washed with kerosene until they are clean, after which the traces of kerosene should be removed and the governor oiled thoroughly with clean, fresh oil. This should remove the trouble of irregular running, if the remainder of the mechanism is in good condition. If the knife-edge blade is worn blunt, so that it fails to engage properly with the push block, the engine will run irregularly; consequently, the knife-edge should be kept sharp enough to engage the push block promptly. The spring by which the blade is drawn into the path of the block may grow weak through continued usage, in which case the blade will not be moved quickly and the engine speed may fall considerably before explosions take place. The remedy for trouble of this

kind is to shorten the spring so as to increase its pull, in case there is no screw adjustment for accomplishing that object. The engine should not take in and explode two charges in successive cycles. An explosion should be followed by one or more idle cycles, and the governor should be adjusted until this end is attained.

MISCELLANEOUS REPAIRS AND RENEWALS

REPAIRING CRACKED WATER-JACKET

58. Neglect in draining the cylinder jacket when stopping the engine after the day's run may result in cracking the outer shell in cold weather, owing to the freezing of the water. It is very seldom that the inner cylinder is damaged in such a case, but if it should happen to be injured, the casting is generally rendered useless and must be replaced with a new one. The outer shell, being much lighter than the cylinder itself, provides a safeguard against damage to the latter, and in most cases, if the cylinder and jacket are cast in one piece, it will be possible and economical to repair the cracked shell.

59. The best and most permanent method of repairing a cracked water-jacket is by means of oxyacetylene or electric welding, in which a new piece of metal is fused with the two sides of the track. This operation should be entrusted only to a person skilled in the use of the welding apparatus, because in welding the crack in the water-jacket, it is necessary to heat the cylinder casting all over, or on the side in which the crack is located. This is done to expand that portion of the casting affected by the welding, so that the cooling metal of the weld will contract without fracture. It is evident, therefore, that the main difficulty connected with the welding of the water-jacket lies not so much in the welding itself, but in properly judging where and how much to heat the casting before the welding operation is started. For this reason, the work should always be done at some shop properly equipped for such work.

60. If a welding outfit is not available, a cracked water-jacket may be repaired in a number of other ways. Fig. 3

(*a*) and (*b*) shows a cylinder, the outer shell of which has been burst by frost. The crack *a b* extends only a portion of the entire length. After the ice has been thawed and the jacket emptied, the first thing to do is to drill two holes *a* and *b*, about $\frac{1}{4}$ inch in diameter, at the ends of the crack. The purpose of these holes is to prevent the crack from extending any farther during the chipping operation. Take a chisel about $\frac{3}{16}$ inch to $\frac{1}{4}$ inch wide and chip a groove along the line of the crack, dovetailed as shown at *c* in view (*b*), the groove being widest at the bottom. Next secure a piece of $\frac{1}{4}$-inch round copper wire, well annealed, and hammer it tightly into the groove. By careful calking a crack of this nature can be made perfectly tight.

61. The crack *d e*, Fig. 3 (*a*), extends from one of the water ports to the outer end of the cylinder. In such a case,

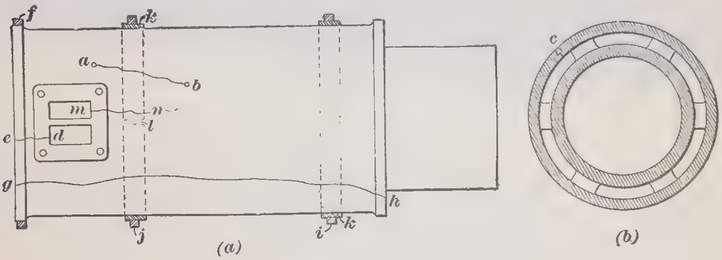


FIG. 3

it is necessary to shrink a steel band *f* on the end of the cylinder, before the crack is chipped out and calked in the manner just referred to. Use a flat steel band about $\frac{1}{2}$ inch by $\frac{3}{8}$ inch in section, and be sure that the finished end of the cylinder projects about $\frac{1}{8}$ inch beyond the band when in place.

If the crack extends over the entire length of the jacket, as shown at *g h*, it will require additional bands *i* and *j* as shown. If the cylinder has finished collars at the ends, as is frequently the case, it will not be possible to slip the ring *j* over the end of the cylinder into its proper place, unless an auxiliary band *k*, open to the extent of about $\frac{1}{4}$ inch as shown at *l*, is first placed on the cylinder. This band *k* must, of course, be thick enough to make up for the difference in diameter of the cylinder body

and the finished collar. In shrinking rings on a cylinder, they should be heated to a dull red heat and must be handled quickly, as the cooling takes place rapidly and the ring may shrink so as to stick before it reaches its position if not applied quickly. After the bands have been put in place and have been found to be tight, the cracks should be grooved and calked as directed.

If a crack should develop in the surface of a joint between the cylinder and one of the valve casings attached to it, and if this crack crosses the port through which the entering charge or the exhaust gases pass, as shown at *m n*, it will be practically impossible to repair the casting in such a manner that a packing can be made to stand, and the only remedy is to replace the damaged part with a new one.

62. Another method of repairing a short crack in the surface of the jacket wall consists in applying a piece of steel boiler plate, about $\frac{1}{8}$ inch thick. Before putting on the plate, two $\frac{1}{4}$-inch holes should be drilled at the ends of the crack, to prevent it from going farther, and a **V**-shaped groove cut along the crack from end to end. The plate must be bent so as to conform to the shape of the cylinder jacket. A packing of thin asbestos wick soaked in white-lead paste is now put in the **V**-shaped groove, after which a packing of sheet asbestos the size of the plate and dipped in water is placed over the surface to be covered by the plate, Now apply the plate, which is held in place by a number of $\frac{1}{4}$-inch to $\frac{3}{8}$-inch screws, the size of the screws depending on the thickness of the water-jacket. The screws should be about 1 inch apart, 1 inch on each side of the crack; and, if possible, the tapped holes in the jacket, in order to prevent water from leaking past the screws, should not be drilled all the way through. If the jacket is so thin as to make it necessary to drill the holes all the way through, each screw head must be packed with hemp or asbestos soaked in white lead.

63. An automobile-engine water-jacket split by freezing is also sometimes repaired by the following methods: If the crack is very small it may be rusted up. For this purpose, a saturated solution of sal ammoniac is made and poured into

the jacket. A plug, screwed into one of the water openings, is drilled and tapped for a small tube, by which air pressure is put on the liquid in the jacket by means of a tire pump. The cylinder is so laid that the crack is at the bottom, and after several hours it will be found that the edges of the crack have rusted solid from the action of the sal ammoniac.

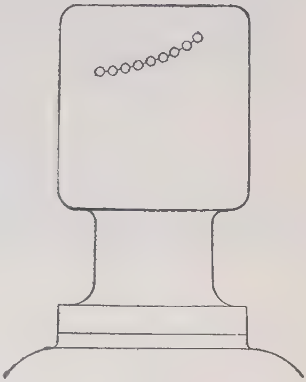


Fig. 4

64. Another method of closing a crack is that shown in Fig. 4. The process is to drill and tap a series of $\frac{1}{8}$- or $\frac{3}{16}$-inch holes as close together as practicable for the entire length of the crack, the first and last holes being at the extreme ends of the crack, in order to prevent it from extending farther. These holes are plugged with cast-iron plugs turned and threaded for the purpose, and the job is completed by rusting in with the sal ammoniac solution as just described.

REPAIRING BROKEN ENGINE BED

65. The breaking of the studs or bolts that hold the connecting-rod box to the rod will often wreck an engine, involving the breaking beyond repair of the piston, cylinder, and even

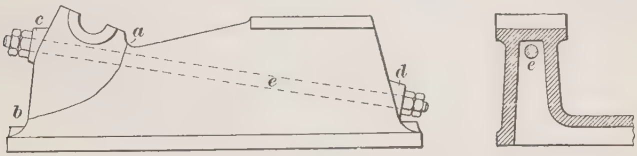


Fig. 5

the bed. As the bed is usually a rather costly part to replace, it is frequently found possible to repair it with the aid of a strong steel rod properly applied. A break repaired in this manner is shown in Fig. 5. It is possible to make this kind of

repair only when there is a clean separation of the casting in two pieces; if the bed is broken into a number of small pieces, it must be replaced with a new casting; or, if the breakage is not too serious, the parts may be welded together by the oxy-acetylene process, referred to in connection with cracked water-jackets. To repair a bed, as shown in Fig. 5, first be careful to preserve the pieces so that they will fit exactly when put together, using every precaution against careless handling and further damage to the surfaces that form the joint. Then investigate and find the best way in which the steel rod should be run so as to take hold of the strongest available part of the bed.

66. The illustration shows the rod running inside of the double-wall casting, a 2-inch rod being used in a space 3 inches wide, and being secured by two nuts at each end. The line *a b*, Fig. 5, indicates the break of the bed casting. At *c* and *d* are cast-iron washers made to conform to the shape of the casting and providing a flat surface for the nuts of the bolts *e* to rest on. It is important that the nuts should bear squarely against these washers to avoid any excessive stress on the bed casting. Jam nuts or some other locking device must be provided to prevent the nuts that hold the bed together from becoming loose as a result of the shocks and jars to which the casting is subjected while the engine is running. A frequent inspection of the tightness of the nuts is advisable.

67. The base of small, vertical, stationary engines sometimes breaks at the corner where the fastening bolt passes through, due to irregularities in the surface upon which the base rests. If the supporting surface is not perfectly smooth, the tightening of the bolts produces a strain at one or more points where the base is fastened, and the vibration set up by the running of the engine will eventually cause a fracture at these points.

A broken corner can be conveniently and effectively repaired as shown in Fig. 6. The plate *a*, which is so shaped as to conform to the contour of the engine base, is made of wrought iron or steel of about $\frac{5}{8}$-inch thickness. A hole is drilled in the

middle, of the right size to make a good fit for the fastening bolt *b*. Holes are drilled at each end for $\frac{5}{8}$-inch studs or cap-screws, and corresponding holes are drilled through the base *c*. The holes in the base are then tapped with a $\frac{5}{8}$-inch tap. The plate is put in place as shown, the studs *d* inserted in the holes

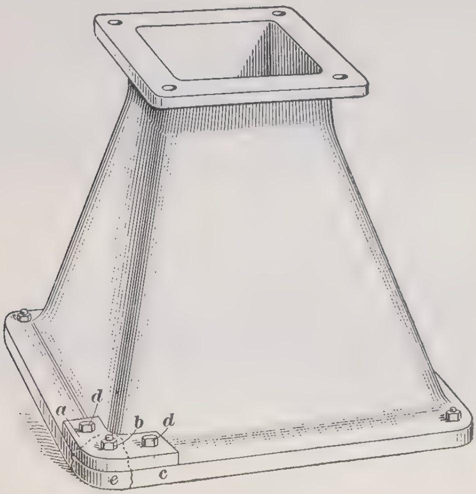


FIG. 6

and screwed tightly into the base *c*. The nut on the fastening bolt *b* is then tightened down, and the broken piece *e* is held firmly in place.

The best repair in this case, as in other cases of broken parts, is by autogenous welding if this can be done conveniently.

REMOVING CARBON FROM CYLINDERS

68. Carbon can be removed from cylinders in a number of ways. If the deposits are soft, they can be removed by a liberal use of kerosene. The kerosene is put into the cylinder just after the engine is shut down and while the cylinder is hot, and is allowed to remain overnight. When the engine is started, the carbon that has been loosened by the kerosene will be blown out with the exhaust gases. However, even with the regular use of kerosene or other decarbonizing materials that

are similar in their action, the carbon will gradually accumulate, and a time will come when the deposits must be thoroughly removed by other methods, such as burning it out or removing it with scraping tools. To burn it out, an outfit like that shown in Fig. 7 is used. It consists of a compressed-oxygen tank *a* fitted with a needle valve *b* and a pressure-reducing valve *c* to which is connected a gauge *d* and a flexible pipe *e* having a piece of copper or brass pipe *f* at the end. Experienced users of this method recommend that the carbon in each cylinder be given a kerosene treatment before the oxygen torch

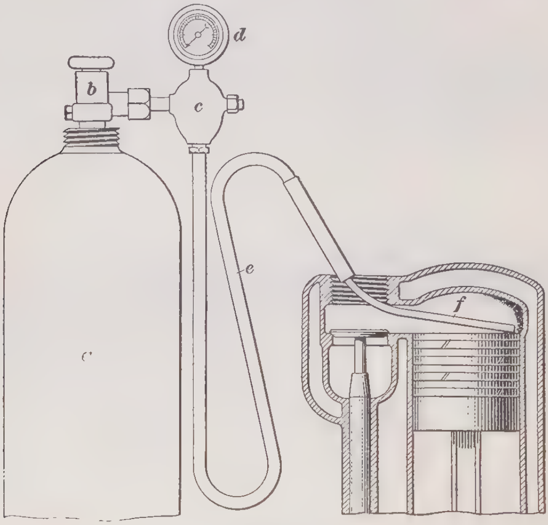


FIG. 7

is employed. The night before the burning-out process is carried on, it is advisable to pour three or four tablespoonfuls of kerosene into each cylinder while the engine is hot, and let it remain there overnight. As a matter of safety, it is also recommended that the gasoline supply be cut off from the carbureter, and the engine run until the gasoline in the supply pipe and float chamber of the carbureter is consumed. This removes the danger of fire.

It is a good practice, also, to remove the spark plug or igniter, as the case may be, from each cylinder, to prevent its

being injured by the high temperature developed when the carbon burns by combining with the oxygen.

69. To use the carbon-burning apparatus, the valve cap is removed, the pipe *f* is inserted into the cylinder, and the valve *b* is opened slowly until the gauge *d* shows a pressure of from 12 to 15 pounds, the exact pressure depending on the design of the torch and the amount of oxygen in the tank *a*. Full instructions accompany each outfit, and these should be followed carefully until the operator is fully familiar with the use of the apparatus. When the oxygen begins to pass into the cylinder, a lighted match is dropped into the chamber, and the pipe *f* moved about briskly in order to cover as large an area as possible. The carbon and the oxygen, in the presence of the match flame, will ignite and burn very rapidly, throwing

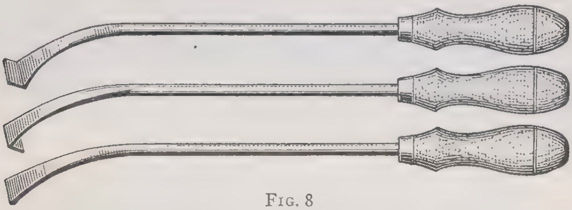


FIG. 8

sparks and flame from the opening. Once the carbon begins to burn, the combustion continues as long as the oxygen flows into the cylinder.

Results have demonstrated that there is little danger of damage to any of the engine parts by the carbon-burning process, but the water-cooling system should be full before the operation is begun.

70. Another common way to remove carbon is to use scrapers. This method will not clean the combustion chamber so thoroughly as the oxygen process, but will give very good results where the other is not convenient. Carbon scrapers can be easily made by any mechanic, but there are available forms on the market which may be obtained at small cost, and have advantages worthy of consideration. The forms shown in Fig. 8 are of this type. To prepare each cylinder for scraping, two or three tablespoonfuls of kerosene or acetone should be

poured into the cylinder, while the engine is hot, and sufficient time allowed for the carbon to soften. The first step in scraping out the carbon is to remove the valve-chamber caps and take out the exhaust valve. The engine is turned over until the piston in the cylinder being worked on is on the upper dead center, or the extreme top of its compression stroke, in which case the inlet valve is closed. The scraping tool is then inserted in one of the valve-cap openings, and drawn back and forth over the surface of the combustion chamber. When the carbon is pretty well loosened, a great deal of it can be removed by using the scraper as a hoe, drawing the carbon into the exhaust-valve chamber, where it will pass out with the exhaust. The remainder can be largely driven out by inserting the nozzle of a compressed-air hose into the opening in the cylinder. If no compressed air is available, a tire pump can be used with good results. A piece of soft cloth should be saturated with kerosene and used to swab out the combustion chamber, after which the exhaust-valve seat is carefully cleaned off, the valve reground, if necessary, and replaced.

71. Removable cylinder heads are very common in modern engines, and these may be taken off to remove the carbon, making possible a more thorough cleaning of the combustion chamber than by any of the other methods. The carbon is first scraped out, care being taken not to score any of the metal surface of the cylinder. A cloth wet with kerosene can then be used to wash out all traces of the carbon. It is a very good practice to grind all of the valves when the operation is finished, to remove the necessity of taking the cylinder head off again at some time in the near future.

GRINDING OF VALVES

72. The length of time that an engine will run before regrinding of the valves is necessary depends on the condition of the engine, and the material of which the valves are made. Inlet valves and their seats will rarely, if ever, be found badly

pitted, but foreign matter often settles on their seats, preventing the valves from seating properly. The exhaust valves, unless made of one of the non-pitting alloy steels, will usually be found pitted after a few months running, although the seats may not be in bad condition. When these valves are made of non-pitting alloy steels, they may become leaky by carbon settling on their seats, in which case a light grinding will serve to make the valves tight again.

After the valve-spring thrust-washer retaining pin, key, or horseshoe collar has been removed, the valve is taken out, the valve stem being pushed with a screwdriver or some other tool until the valve head can be grasped by the fingers. When caged valves are used in the engine, the cages are removed and the grinding process carried on in a vise. With removable cylinder heads, the head can be taken off and placed on the floor, a bench, or any other convenient place for doing the grinding.

73. If the valve is badly worn and scored, which will be shown by a blackening of the valve and seat, it may be necessary to reseat and true up the valve; but if the engine has had fair care and attention, grinding should be sufficient. The usual method of performing this operation is to rotate the valve on its seat, first covering the seat with some form of grinding material, such as emery, carborundum, powdered oilstone, ground glass, or the fine dirt that accumulates under a grindstone. These valve-grinding compounds, properly mixed with grease to form a paste, can be obtained from any automobile supply house. The compound is applied thinly to the surface of the valve and its seat. Extreme care must be taken to prevent any of the emery from getting into the interior of the cylinder, where it would quickly ruin the piston and the cylinder walls. In some cases, a plug of waste can be thrust into the valve chamber between the valve and the piston; but, if the chamber is not long enough for this, the work will have to be watched carefully, using an electric light, if necessary, to see that none of the paste works away from the valve toward the piston.

The valve may be rotated by a brace *a*, Fig. 9, carrying a screwdriver *b* that fits into the slot in the upper face of the valve *c*. If no brace is handy, an ordinary screwdriver will serve, the screwdriver being held vertical and rotated back and forth through part of a revolution by rolling it between the palms of the hands, one hand being placed on each side of the handle. Only a very light pressure should be put on the valve during the grinding operation.

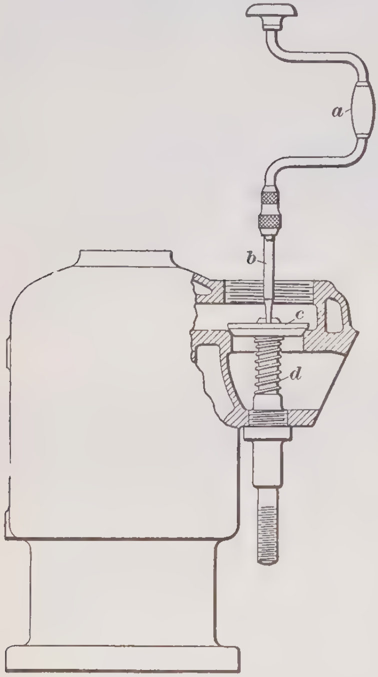


Fig. 9

The valve should be oscillated, or turned back and forth, and not rotated continuously in one direction. Also, it should be lifted frequently and turned so as to prevent the grinding from becoming too great at any one point. If a light coiled spring *d* is dropped over the stem before grinding is begun this spring will lift the valve slightly whenever the pressure is removed, and it can then be turned so as to bring new surfaces into contact with each other. If the valve is badly scored, the first grinding may be done with coarse material, the final finishing being done with finer grades of grinding material. If the valve has been fitted, it will not be necessary to grind it until the pits have entirely disappeared, so long as there is a good bearing around them. When the work is finished, the ground portion of the valve should have a smooth, dull appearance, and neither the valve nor its seat should at any point be bright, as this would indicate that metal had been rubbing on metal without emery between.

74. In case the head of the valve is not slotted for a screw-driver, but has two holes for a pin wrench, such a wrench must be used, which can be made by any machinist or blacksmith, or in an emergency can even be improvised from a round piece of hardwood into one end of which two wire nails are driven the right distance apart.

75. Before the valve is finally replaced in position the stem should have all carbon or scale scraped off, and then be rubbed clean with a very fine grade of emery cloth, and washed with kerosene. The valve seat must be washed clean with a piece of soft cloth saturated with gasoline, so that no traces of the abrasive will remain.

76. If it should be found when grinding valves that the end of the valve stem bears against the end of the valve lifter even when the engine has been turned over so that the other end of the valve lifter rides on the concentric part of the cam, the adjusting screw of the valve lifter must be screwed down until the valve stem clears, because otherwise the valve cannot be ground to its seat.

After valve grinding, the clearance of all valves must be adjusted again.

When valves and valve seats are very deeply pitted, the valves should be faced off in a lathe or a valve-turning tool, and the valve seats should be machined by means of a valve-seat reamer, which can be obtained from any automobile supply house. The valves may then be ground in.

77. In an old motor it may be found that the bushing or sleeve in which the valve stem runs is worn to such an extent as to permit considerable sidewise movement of the stem. A valve in this condition will still operate if it has been carefully ground, but it is likely to need grinding much oftener than if it were truly guided by its bearing. It should never be ground with the spring washer merely blocked up; the spring should in each case be wholly removed.

VALVE SETTING

78. The simplest case of timing poppet valves arises when the clearance between the ends of the valve stems and valve lifters is to be adjusted, and when the cam-shaft has not been removed from the engine, so that the cam-shaft is still properly timed in reference to the crank-shaft. In this work, unless extreme accuracy is desired, no reference need be made to the marks on the flywheel showing the time of opening and closing of the valves. Retiming of the valves, under the conditions stated, should not be attempted until the valves have been ground to their seats, as frequently one or more of the valves do not close entirely on account of carbon particles or dirt lodged beneath them. Also, before retiming is attempted the valve springs must be replaced.

Beginning at one end of the engine, the engine is cranked slowly by hand until one valve, say the inlet valve of cylinder 1, is seen to have closed, as evidenced either by noting a small gap or clearance between the valve stem and valve lifter, or valve stem and valve rocker-arm in case of overhead valves operated by rocker-arms, or the valve having stopped moving. The crank-shaft is then rotated slightly further to make sure the valve lifter is riding on the concentric part of the cam. Now, by means of the adjusting screw and locknut provided on valve lifters of the better class of engines, the clearance is adjusted to the amount called for by the maker of the engine, which varies from .002 to .005 inch on **L**-head and **T**-head motors to as much as .01 inch on motors with overhead valves. A clearance must be left between the valve stem and its operating mechanism to allow for the expansion of the stem by heat. The clearance can be adjusted to suit a piece of paper of the proper thickness. Ordinary letter paper used for business forms is from .004 to .005 inch thick. The strip of paper is inserted between the bottom of the valve stem and the adjusting screw, and the screw is turned until the paper is just pinched. The adjusting screw is then locked firmly in place by means of the locknut that is provided for that purpose.

79. The time of opening and closing of the valve varies according to the design of the engine, but must not vary between one cylinder and another cylinder of the same engine. There are many things that may cause unequal valve action. The cam-shaft may get slightly sprung or twisted, its bearings may become worn out of position, one cam may wear faster than another, due to unequal hardening, and the various contact points between the cam and the valve may become worn; all of which affect the evenness of the valve operation.

80. If the cam-shaft is twisted or the cams are unevenly worn, a new cam-shaft should be installed. If it is sprung it can often be straightened by putting it between the centers of a lathe with the high side down. While in this position, it should be sprung up by means of a lever, and peened on the upper side by light hammer blows. The peening is made more effective if the shaft is heated with a torch just hot enough so that the oil on it begins to smoke. It must not be heated hotter than this or the hardened surface is liable to lose its temper. Heating to such an extent that coloring appears on the bright surface is injurious. If the fastening of the driving gear is loose, it can usually be remedied by a tight-fitting new key. The wear of the gear-teeth should be watched to guard against the possibility of a broken tooth, because an improperly hardened gear wears very rapidly.

BROKEN CRANK-SHAFT

81. Occasionally a stationary gas engine will be noticed in operation with the crank-shaft jumping in one or both journal-boxes at each impulse of the piston, indicating that the bearings are loose. These loose bearings eventually result in a broken crank-shaft. Broken crank-shafts would be comparatively rare if the bearings were more carefully looked after and kept properly adjusted. The sudden force applied to the piston by the explosion of the charge in the cylinder tends to lift the crank-shaft out of its bearings when the engine is turning over, even with the weight of the heavy flywheel or wheels

tending to hold it down. If the bearings are tight, and fit properly, this lifting motion cannot occur, but if the caps are loose, each impulse raises the shaft and flywheel, or wheels, and as soon as the force of the impulse subsides, the weight causes the shaft to drop again with a thump. If only one bearing is loose, and the other is properly adjusted, only the loose end of the shaft will jump, and thus be thrown out of line at each impulse. This condition is even worse than when both bearings are loose, and is often the cause of a broken crank-shaft.

The crank-shaft seldom breaks at the first appearance of the loose bearing; the conditions that cause the break have usually been in existence for some time before the final rupture occurs. The undue strain on the shaft every time it jumps in the bearings and the continual heavy strain at regular intervals, cause a crystallized condition in that part of the shaft where the greatest strain occurs. A crack is started at this point, and finally the shaft reaches such a stage that it is no longer able to carry the load, and breaks. To avoid trouble of this nature, it is necessary only to give the proper attention to the bearings, or to see that they fit properly and are sufficiently lubricated.

RENEWING BABBITT-METAL LINERS IN STATIONARY ENGINES

82. When a babbitt-lined bearing becomes overheated and the trouble is not noticed in time, the soft metal of the lining, which may have a tin or a lead base, will melt and run out of the box. While in some stationary engines the Babbitt metal is cast directly in the rough bearings of the engine bed, it is the general practice in a first-class engine to bore out the bearings in the bed and fit them with cast-iron or bronze boxes lined with Babbitt metal.

83. If the journals of the shaft are in good condition after the metal has been melted and run out of the box, the method of rebabbitting the bearing is the same as was followed at the time the box was made at the factory. To reline the box in such a case, proceed as follows: Remove all traces of the

original lining from the box. While melting the new metal in the ladle, place the box on its end on a flat-finished surface, and insert an arbor, from $\frac{1}{8}$ to $\frac{1}{4}$ inch smaller in diameter than the journal, in the center of the box, being careful to have an evenly divided space all around the outside of the arbor. This can be done by placing at each end of each box a little strip of leather about $\frac{1}{4}$ inch wide, and long enough to encircle the shaft. The box being made in halves, as shown at *a*, Fig. 10, place shims *b*, made of cardboard $\frac{1}{32}$ inch thick, between the joints, having the shims extend well into the space around the arbor

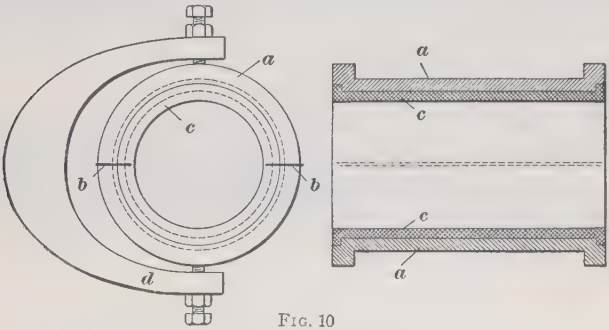


FIG. 10

so as to allow only a thin strip of the Babbitt liner *c* to connect the halves of the lining, in order to facilitate the breaking apart of the lining after it has been cast.

84. It is well to heat the box to a moderate temperature before the Babbitt metal is poured into it, as this will aid in the free flow of the molten metal. After being put in position, apply clamps *d* to hold the halves of the box together. Then pour the Babbitt metal into the box until it is full, and, after allowing it to cool, take off the clamps and separate the box. The metal is then peened with the ball-shaped end of a machinist's hammer, until it adheres firmly to the box. The joints are then dressed so as to be flush with the parting of the box. After clamping the halves together, the box is bored in a machine shop to the size of the journal, or, rather, to a small fraction of an inch smaller than the journal, so as to allow a perfect fit to be made by scraping the box by hand.

85. If the journals of the shaft are damaged during the heating and melting of the Babbitt metal, the shaft must be taken to a machine shop and the journals be trued up before the new lining is prepared. The same should be done if the journal has become unevenly worn or if it shows flat spots. If the wear of the shaft is limited to unevenness of the diameter at various points of the length of the bearing, it may be sufficient to pour the Babbitt metal around the shaft itself, instead of using the arbor as just explained. In such a case, it is best to place the shaft in the engine bed and close up the ends of the space around the journal with wet fireclay, so as to prevent the Babbitt metal from running out at these points while it is being poured. The same method should be pursued if the Babbitt lining is poured directly in the engine bed. Care must be taken in all cases that the box or bearing is perfectly dry before any hot metal is poured, to avoid sputtering of the metal and possible injury to the operator.

FITTING CRANK-SHAFT BEARINGS

86. In nearly all modern high-speed engines as used in automobile or aeroplane service, access is gained to the crank-shaft bearings by removing the crank-case. A jack can be employed to good advantage in removing the crank-case from an automobile engine, by placing it directly under the middle of the case and raising it until the head is tight against the case. The jack will then hold the crank-case firmly in position until all the retaining bolts or capscrews are removed, and can then be lowered, letting the crank-case down with it to such a point that it can be easily withdrawn from under the car. With the crank-case removed, it is an easy matter to examine the condition of the main crank-shaft and connecting-rod bearings.

87. Connecting-Rod Bearings.—The connecting-rod bearings wear more quickly than the main crank-shaft owing to the greater unit stress to which they are subjected, and it may be necessary to take these up. The amount of this wear

can be determined by grasping the connecting-rod firmly and moving it up and down. The connecting-rods can be removed by taking out of each the capscrews or bolts that fasten the cap to the main body of the connecting-rod. If there is only slight wear between the bearing and its journal, this can be taken up by removing one or more of the thin shims, or liners, ordinarily used to separate the bearing caps from the seat. Care must be taken to remove an even number of shims of equal thickness from each side of the bearing. If no shims are provided, the sides of the bearing must be filed or planed down to provide clearance and shims should be installed when replacing the bearing. The same amount of metal must be taken from each side of the bearing. If there is considerable lost motion after one or two shims have been removed from

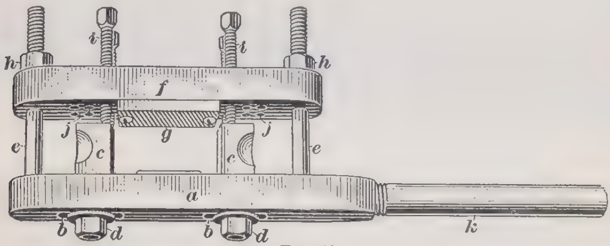


Fig. 11

each side, or if the crankpins or their bearings are cut and scored, it is advisable to scrape the bearing to a fit before the bearing cap is tightened up. Before this is done, however, the crankpins must be smoothed up and tested for roundness. In case they are out of round they must be trued up carefully, as otherwise the bearing will soon wear loose again, resulting in a noisy engine.

88. A very useful device by the use of which the crankpins of an engine can be trued up without removing the crank-shaft from the engine is shown in Fig. 11.

It is simple in construction and does extremely good work when carefully manipulated by a competent mechanic. It consists of a base *a* having slots *b* provided for the adjustment of the sliding blocks *c*, which are firmly fastened, when set in the

proper positions, by the retaining nuts *d*. Two upright posts *e* support the bar *f* which carries the cutting tool *g*, the nuts *h* serving as adjusting nuts to give the proper pressure of the cutting tool on the crankpin. The cutter *g* is very similar in appearance to a section of a mill file. Four long setscrews *i* passing through the bar *f* can be screwed against the blocks *c* when the shaft is in place, to steady the cutter and make possible a smoother job. The positions of these screws can be changed by screwing them into other holes *j*, which are provided for this purpose. A removable handle is shown at *k*. When using the tool with the crank-shaft in place in the engine, the handle must be removed so that the tool can be turned through a complete revolution.

89. If the crankpin is badly scored or is very much out of round, the pin should first be filed carefully with a very fine file until it is very nearly round and the surface is practically free from score marks. The finishing tool may then be used to complete the operation. To use the tool, the nuts *h* and bar *f* are removed, and the device is placed in position on the crankpin. The nuts *d* are loosened, the blocks *c* are set up against the crankpin, and the nuts tightened. The bar *f* with its cutter *g* is then replaced on the upright posts *e* and the adjusting nuts *h* are screwed down lightly with the fingers. Unless the crankpin is badly out of round, it will not be necessary to use the setscrews *i* and these may be left clear of the blocks *c*. The tool is then turned slowly by hand with a side to side as well as a rotary motion. The tool must not be turned around in one spot, as there is danger of grooves being cut into the crankpin. Care must be taken, also, to turn the tool in the right direction, as the cutter will cut in one direction only. After the tool has been rotated a few times, scraping off a very light surface from the pin, the bar *f* must be removed and the teeth of the cutter cleaned of all metal. The operation is then repeated as often as is necessary to obtain an even, round surface. This may require some time, but exceedingly accurate results are possible when the tool is operated properly.

90. After the finishing tool is removed, the surface of the crankpin can be smoothed up and polished by means of a lapping tool such as is illustrated in Fig. 12. Two pieces of hard wood, of width equal to about one-half the length of the pin, are drilled and bolted together, and a hole *a* is bored to the size of the bearing. An abrasive paste composed of fine powdered emery and oil is placed in the lap, and the blocks are then clamped to the crankpin. A side-to-side and rotary movement is then given to the lap, and new abrasive added from time to time until the desired polished surface is obtained, after which the pin must be cleaned of all abrasive with gasoline.

91. The main crank-shaft journals may be trued up in the same manner as the crankpins, but in this case the crank-shaft must be removed from the engine. The handle *k*, Fig. 11, of the truing device can then be used to advantage. The main journals do not wear out of round so rapidly as the crankpins because the wear is more evenly distributed, and, therefore, the truing up of these journals is not often required.

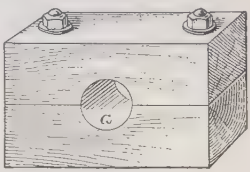


Fig. 12

92. After the crankpins are trued up properly, the connecting-rod bearings must be fitted to the pins. In order to bring the brasses closer together it may be necessary to remove some metal from each side, and sufficient metal should be removed to permit of the use of shims when the cap is placed in position. To insure a good fit of the bearings, they must be scraped, and while this scraping is a tedious operation, a good job can be done with a certain amount of care and patience. Prussian blue pigment should be spread evenly and thinly over the entire surface of the crankpin, and the bearing then put in place and tightened up with its retaining bolts. The crank-shaft is then revolved several times, after which the bearing cap is removed and the high spots noted. These spots are indicated by the presence of blue marks on the inner face of the bearing, and these marks must be scraped off carefully

with a bearing scraper. At the beginning of the scraping process the bearing may seat at only a few points, but continued scraping will finally result in a bearing being indicated all over, when it may be considered finished. The upper bearing, which must be scraped at the same time as the cap, can be removed by withdrawing the piston either through the top, when the engine has a removable head, or through the crank-case. The brasses must have about $\frac{1}{64}$ inch end play, and must not bear on the rounded corner or fillet at the ends of the crank-pins.

93. In replacing the bearings, the nuts must be drawn up tight and shims must be used to obtain the correct adjustment. In aeroplane engines, it is the usual practice to have the bearings fit loosely, with .002 to .004 inch clearance, and to maintain the oil film by forcing a large amount of oil through the bearings under very high pressure. The higher the pressure of the oil, the looser the bearings can be. For example, when the bearing is carefully scraped and fitted to the shaft, a .002-inch shim should be placed in each side of the bearing to loosen it up, when a high-pressure oiling system is employed. If the system is of a comparatively lower pressure, the bearings must be adjusted closer, or they will hammer out. Newly scraped bearings must be adjusted closer than old ones that are already worn smooth, as the shaft will touch the bearings in only comparatively small spots, and these spots will wear very quickly until the bearing is worn to a fit.

In automobile engines, the bearings are usually so adjusted that the connecting-rod will just swing of its own weight.

GASKET TROUBLES

94. Cylinder-Packing Troubles.—The joints between the cylinder head and the cylinder of stationary gas engines are kept tight by a specially prepared copper-asbestos gasket. When the gasket is damaged by overheating or excessive pressure, water from the jacket leaks either to the outside or into the cylinder. The latter is the more serious leak of the two,

as it interferes with the running of the engine by corroding the points of contact on the igniter or spark plug and the valve seats and stems, and prevents proper lubrication of the piston and cylinder. Leaking toward the cylinder is generally indicated by splashing of the cooling water at the overflow pipe when the explosion takes place.

95. In most cases, the blowing out of a gasket is caused by the combustion pressure opening the joint between the packing surfaces, the packing being heated and partly destroyed, and allowing water to enter the combustion chamber. A partial or complete stoppage of the cooling-water supply or the clogging of the water spaces with lime or similar deposits will also result in the overheating of the cylinder and consequent damage to the packings.

As soon as a leak of water from a faulty packing develops, preparations should be made to renew the packing at the first opportunity. If the leak is to the outside, which may not interfere with the operation of the engine, although it will cause inconvenience through having to catch the water in buckets, it is not necessary to shut down the engine until the day's work is done. If the leak is toward the combustion chamber, the engine will generally stop in a short time.

96. There are various reasons for the failure of gaskets. They may have been made of unsuitable material, the bolts may have been tightened irregularly, or there may have been defects in the gaskets originally. In modern engines with bolted-on cylinder heads, copper-asbestos gaskets are used. These consist of an asbestos center cut to shape by dies and surrounded by thin sheet copper pressed over the asbestos. This type of gasket can be used repeatedly, if care is taken not to bend or break it when removing it. It is usually cheaper in the end to use a new gasket, but if the old one is to be used, it should be annealed by heating it to a red heat and then allowing it to cool slowly, before being put in place. Another widely used form of gasket is the wire-woven asbestos gasket, consisting of asbestos having a fine wire gauze woven into it to give it strength. Ordinary sheet asbestos has so little strength that

gaskets cut from it are of little service. In an emergency, gaskets for cylinder heads may be made from heavy manila wrapping paper coated on both sides with shellac just before they are put in place.

97. To renew a gasket, remove the nuts or bolts that hold the valve chamber or cylinder head to the cylinder, and carefully clean the metal surfaces of any parts of the old packing, using a scraper or a similar tool, but being careful not to mar the surfaces. If the packing has blown out repeatedly, it is advisable to examine the condition of the surfaces and ascertain whether they are true and have not been warped by heat or drawn out of shape by excessive tightening of the bolts or studs.

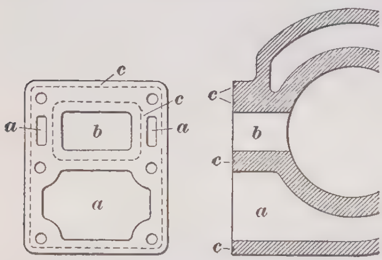


Fig. 13

98. If it is found that the metal surfaces are not true, they must be put in good condition by filing, or, better, by scraping, using a surface plate covered with a thin layer of red lead and oil for determining the high spots. In case studs are used in the cylinder, they must, of course, be removed before the surface on the cylinder can be trued up. The scraping must be continued until the test with the surface plate shows that the packing will have a perfectly straight and evenly bearing metal surface around the water ports *a* and combustion-chamber port *b*, Fig. 13, to rest against. The portion of the surface immediately surrounding the combustion-chamber port *b*, where the pressure is highest, should bear a little harder than the rest of the surface.

99. After the faces of the flanges have been put in proper condition, cut the new gasket from a suitable thickness of asbestos sheet, being careful to have the opening that corresponds with the port communicating with the combustion chamber large enough to allow no portion of the edge of this hole in the gasket to project over the joint. Such projections of the packing material will become incandescent and produce

back firing or premature combustion of the charge. Put back in place the studs that hold the valve casing to the cylinder, apply a coat of flake graphite to the side of the gasket that is to rest against the valve casing, and carefully slide the gasket over the studs until it bears against the metal surface. Then attach the valve or cylinder head to the cylinder, screw the nuts on the studs, and tighten them gradually and evenly.

100. Many times a cylinder-head gasket will leak when the retaining screws have been screwed down tight, even with a new gasket, because the pressure was not exerted evenly throughout the entire surface of the gasket. After the cylinder head is put in place on the cylinder body, with the gasket properly inserted between, the capscrews should be put in and screwed down lightly, alternating from a screw on one side of the cylinder head to one on the other. When the screws are all fairly tight, the operation should be repeated, alternating as before, until the screws are firmly set in place. After everything has been put in order, start the engine and run it under a light load or idle, until it begins to warm up, when it is found that the nuts can be tightened up still more. This should be done promptly, as neglect to take up any expansion resulting from the heat of the combustion may cause the new gasket to become leaky soon after it has been put in.

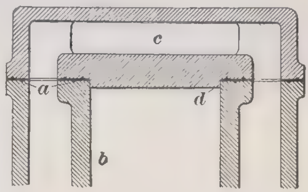


Fig. 14

101. While the faces of the flanges must be true and straight, it does not follow that they should be as smooth as glass. Experience has shown that a grooved surface gives much better results than a perfectly smooth one, although many manufacturers seem to take great pains to make the surfaces as smooth as possible. In many cases, troublesome joints have been permanently cured by the judicious application of grooves in the metal surfaces. The packing fills the grooves and prevents the escape of gas between the surfaces. Fig. 13 shows, by dotted lines, the positions of the grooves *c*, which in

small surfaces may be $\frac{1}{32}$ inch deep and $\frac{1}{16}$ inch wide. On circular surfaces, such as the surface between the cylinder and the cylinder head, shown in Fig. 14, the grooves should be cut concentric, and should not come opposite each other; but, when placed together, the groove *a* in the cylinder *b* should be half way between the grooves in the head *c*, as shown.

102. Whenever possible, the edge of the packing should be protected against the pressure by a projecting rim *d* that enters the end of the cylinder, as shown in Fig. 14. If not originally provided by the maker of the engine, it will pay the user to have the rim attached by riveting it to the cylinder head, in case of persistent trouble with the packing of this joint. The depth of the projection *d* should be about $\frac{1}{4}$ inch, and it should fit rather snugly in the bore of the cylinder, but not so that much force will be required to insert the head.

103. As the material employed for gaskets is usually copper-bound asbestos, or asbestos with an insertion of wire gauze, a knife or a pair of scissors makes very little impression on the latter; but it can be cut out very readily if the sheet is laid on the cylinder head and hammered carefully over the sharp edges of the casting with the flat face of a light, round-peen hammer. The holes for the bolts can be cut in like manner with the round peen. Great care should be exercised not to pull out any wires from gaskets in which wire gauze is used. The wires should be cut off very carefully.

If the material used is ordinary asbestos sheet $\frac{1}{100}$, $\frac{1}{64}$, $\frac{1}{32}$, or even $\frac{1}{16}$ inch thick, it should be thoroughly soaked in linseed oil, either raw or boiled, and dusted carefully with powdered or flake graphite, or with graphite foundry facing that contains talc, etc., which is a very good substitute. It is a good plan to let this dry a little while in the air, when it becomes much tougher. It should not, however, be allowed to get too dry.

104. After the gasket has been put in place, the holding nuts should be screwed down carefully, by going over them several times and screwing down opposite nuts instead of

adjoining ones. The engine should then be started and run a few minutes, and the circulating water turned off, in order to heat up the engine and assist in drying out the oil or any dampness in the gasket. The nuts should then be tightened carefully, when the water may safely be turned on. If these directions are followed closely, and the gasket is not defective, it should last a long time. The oxidation of the linseed oil will make the gasket tough, and if it is dusted with graphite every time the cylinder head is removed it should be very durable.

In using a gasket of asbestos and wire gauze having material on one side to make it adhere to the cylinder top, the opposite side being treated with graphite, there is no need of treating the gasket with linseed oil. A gasket of this sort is almost indestructible when care is exercised in tightening the holding nuts when the gasket is new. In places where gaskets are not exposed to great heat, as between the upper and lower halves of the crank-case, a good, heavy quality of paper can be used. The paper is held in place and cut out to the proper form by tapping it with a peening hammer. Both sides of the paper should be given a good coat of shellac before it is placed in the engine.

POWER DETERMINATIONS

GAS-ENGINE TESTING

EQUIPMENT FOR TESTING

OBJECT OF TEST

1. There are occasions when it is necessary or advisable to make a careful study of the performance of a gas engine under various conditions of working. When introducing a new type of engine or after making improvements on an old one, a manufacturer may wish to know the relative gain in power and efficiency. The manufacturer may also desire a record, showing the results of tests made before the engine left the shop, in order to offset possible complaints from purchasers regarding the non-fulfilment of the requirements of contracts. A prospective buyer may want a test made for purposes of comparison with other engines, or of determining the make best suited to his needs. A user may have trouble with his gas engine and make a test to locate the difficulty, and, after repairs are made, make another test to ascertain whether the engine is in order. In cases like these, a properly conducted test of the engine will bring out the desired information as nothing else will. A thorough test will enable the engineer to determine whether the engine is wasting power, and, if so, to discover the cause; to ascertain whether the engine is correctly designed with regard to the sizes and proportions of valves and passages, and whether the valves are properly set; and to locate

many other faults that would probably be overlooked and that continuous running would perhaps never reveal.

2. While a large amount of useful information can usually be obtained from a complete test, it is not always necessary. Perhaps all that may be desired will be the power that the engine can deliver to the machinery it is intended to drive, in which case some form of brake or dynamometer may be used to measure the power. Sometimes it is desirable to verify the valve setting and ignition timing, in which case diagrams made by an instrument called an indicator may be used. In order that every detail may be understood, however, a test in its entirety will be described; but in practice some of the more essential portions only may be needed.

3. In a gas-engine test, the following results are usually determined in order that the performance of the engine may be ascertained: (*a*) The brake horsepower; (*b*) the indicated horsepower; (*c*) the fuel consumption per brake or indicated horsepower per hour; and (*d*) the lost energy due to heat carried away through the exhaust, by jacket water, and by radiation from various parts of the engine. From the measurements that must be taken to obtain these results the performance of any engine can be readily analyzed.

The **brake horsepower,** abbreviated B. H. P., so called because it is measured by means of a brake, is the name given to the power delivered by the engine to the belt on its driving pulley, or that is transmitted along the shaft in a direct-connected installation. The brake horsepower is frequently called the **delivered horsepower,** abbreviated D. H. P.

The **indicated horsepower,** abbreviated I. H. P., so called because it is measured by means of an indicator, is the power applied to the piston of the engine by the combustion of the fuel in the cylinder and the expansion of the gases.

The **friction horsepower,** abbreviated F. H. P., is the power required to overcome the friction of the moving parts of the engine. It is equal to the difference between the indicated horsepower and the brake horsepower.

TEST APPARATUS

4. Prony Brake.—In making a test to obtain the results indicated in Art. **3,** the brake horsepower is determined by an apparatus similar to that shown in Fig. 1, in which is a view of a form of absorption dynamometer known as the **Prony brake.** It consists of an iron strap *a*, to which are attached, with screws, a number of wooden friction blocks *b*. To each end of the strap is bolted a cast-iron block *c*, so that the brake may be tightened by means of the bolt *d* and the nut *e*. Bolted to *a* are two boards *f*, forming the lever arm, or brake arm, and carrying at one end the steel knife edge *g*. This knife edge rests on a flat piece of iron *h*, through which the pressure is transmitted to the platform scale *k* by means of the stand *j*.

5. Rope Brake.—A simpler form of brake, and one suitable for light powers, is shown in Fig. 2. The brake proper consists of four or five ropes, as shown at *r*, or a piece of leather or canvas belting. The weight *w* is fastened to one end of the belt and a spring balance *b* to the other. The lower end of the balance is attached to a hook *h* screwed fast to the floor. If the pulley were perfectly free to turn, the reading on the spring balance would be equal to the weight of *w*; that is, if the weight of *w* is 50 pounds, the pointer on the balance will be at 50.

As the pulley is turned by the engine, the weight *w* is drawn upwards by the friction of the strap until the strap slips on the pulley. The total amount of pull will then be indicated by the decrease in the reading of the balance, or by the difference between the weight of *w* and the balance reading. Thus, if the balance reads 20 pounds, the pull on the belt will be $w-20$, or $50-20=30$ pounds.

6. Water-Cooled Brake.—It is evident that, in either the Prony brake or the rope brake, the energy absorbed is converted into heat by overcoming the frictional resistance between the brake and the revolving wheel. In the simple forms of brake mentioned, it is a serious problem to take care of the heat generated at high speeds and heavy loads, and for

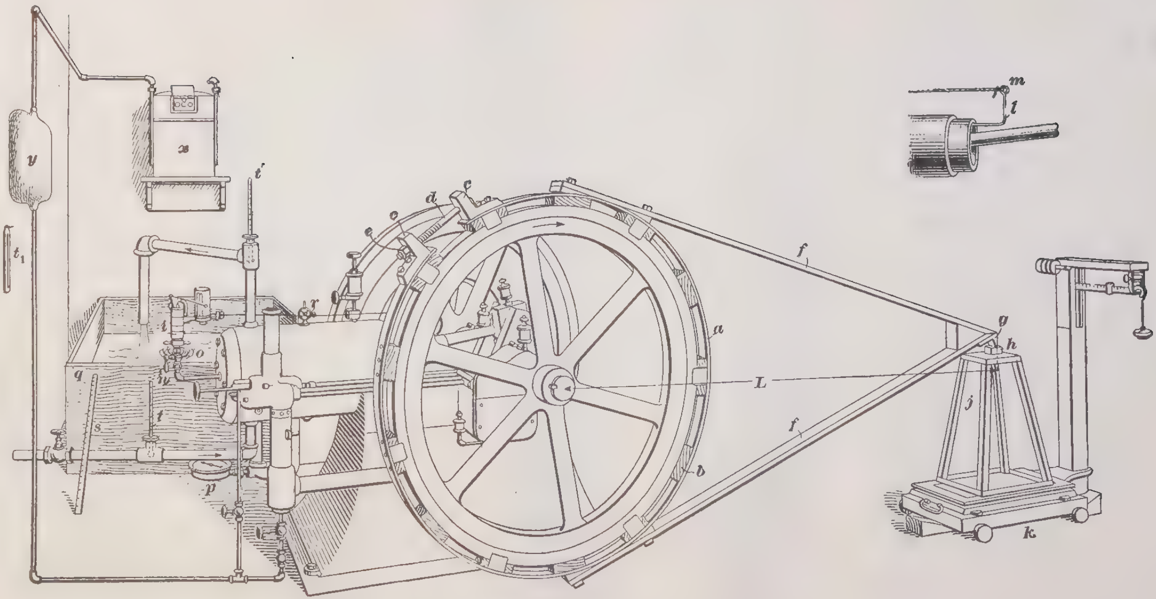


FIG. 1

this reason such brakes cannot be used on gas engines, except for short periods of time, unless there is some means provided to carry off the heat produced. This may be done very simply by using a brake wheel that has two wide flanges cast on the inside of the rim at each edge. The rim thus becomes a trough into which water can be run to absorb the heat generated by the friction. Such an arrangement is shown in Fig. 3. The curved pipe at the left delivers a stream of water into the trough of the rim, in the direction in which the wheel is moving at that point. A second pipe, with a scoop formed at its end, and pointing in the opposite direction to the motion of the wheel, removes the water, so that a continuous circulation can be maintained. The centrifugal force due to the rapid rotation of the wheel keeps the water distributed in an even layer around the inside of the trough-shaped rim.

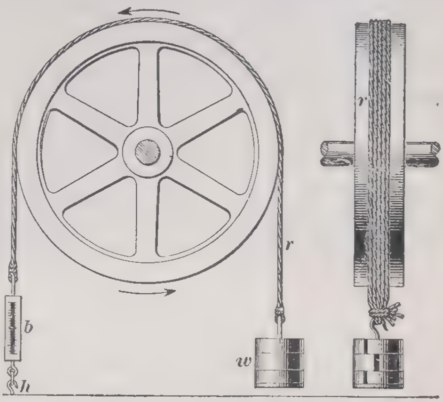


FIG. 2

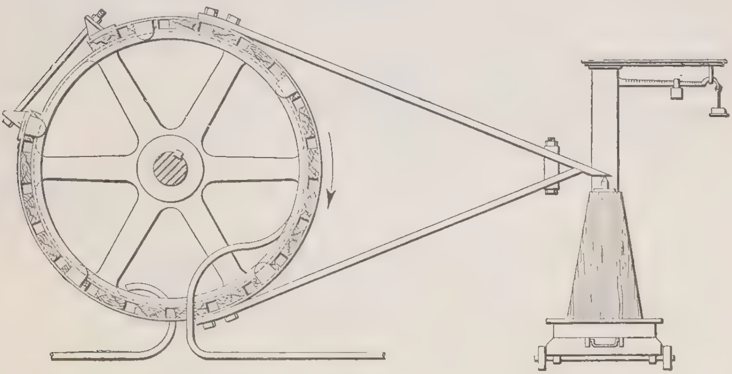


FIG. 3

7. Alden Dynamometer.—The **Alden dynamometer** is a type of brake that can be run continuously with very little attention. An elevation and a part section of such a dynamometer are shown in Fig. 4. It consists of the hub and disk casting *a*, the shaft *b* to which the casting is keyed, the housing plates *c*, and the thin copper plates *d*. The copper plates are clamped at the outer edges between the two housing plates and at the inner edges between rings and the hubs of the housing plates. The copper plates are thus held parallel and close to the disk *a*, in which are radial oil grooves for conducting oil all over the bearing surface between the disk and the copper plates. Oil is fed to these grooves from the oil cups *e*, through the pipes *f* and the oil passages *g* in the housing hubs. The oil that works its way out around the hub to the recesses *h* is drained off through the pipes *i*. The copper plates and the housing plates form chambers *j*, which are filled with running water when the apparatus is in use. Water enters the bottom of these chambers through the pipe *k*, the automatic regulating valve *l*, and the pipe *m*. From the pipe *m*, the water passes through openings in the bottom casting *n* into the chambers *j* in the housing. The water fills the chambers, rises into the space *o*, and flows out through the pipe *p*. The water pressure in the chambers *j* forces the copper plates against the disk *a*, and sets up a friction that heats the copper plates and tends to turn them with the disk. The heat is carried off by the water, while the tendency of the copper plates and housing to turn is balanced and weighed by the weight *q* on the arm *r*. If the water pressure increases, the arm *r* goes up and partly closes the automatic valve *l*, thus restoring the equilibrium.

Dynamometers of the Alden type have been built with three or four disks and large enough to absorb from 2,000 to 3,000 horsepower at from 200 to 300 revolutions per minute.

8. Dynamo as Dynamometer.—Another way to determine the delivered horsepower of a gas engine is to connect the engine to a dynamo and then measure the electrical energy given out by the dynamo when driven by the engine. The

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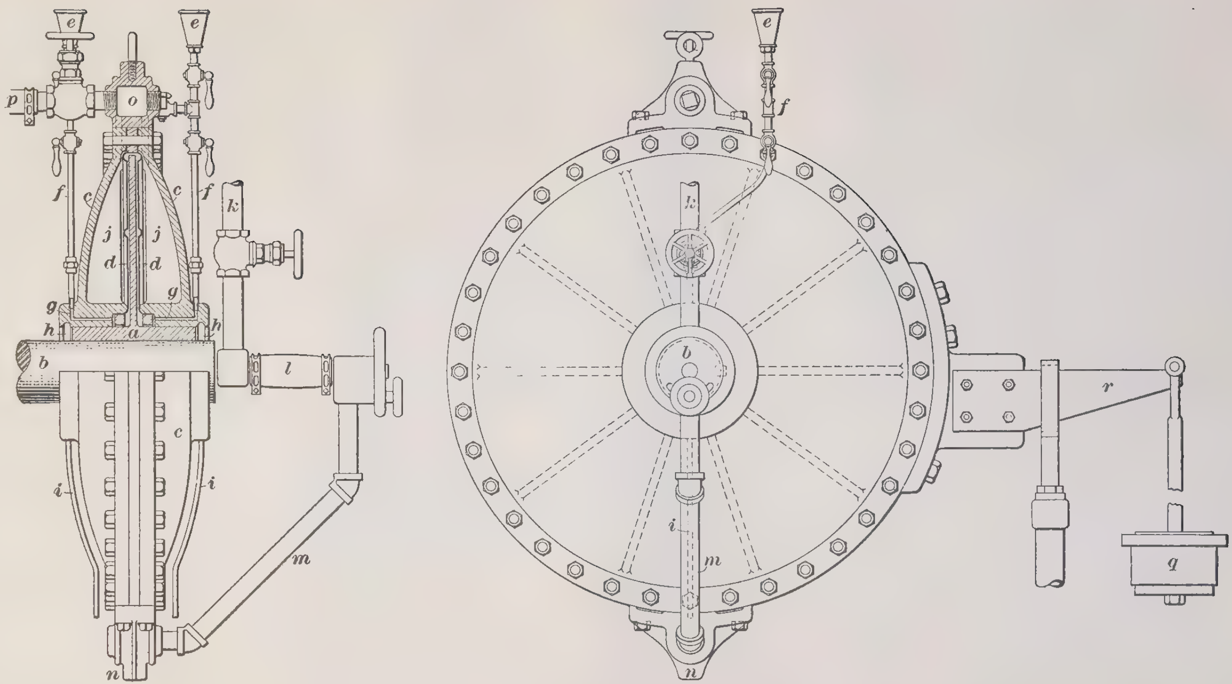


FIG. 4

engine shaft is coupled directly to the shaft of the dynamo; that is, they are direct-connected. The work done by the engine then causes the dynamo to generate electrical energy in the form of a current, which may be absorbed by passing it through a suitable resistance. However, not all of the energy given by the engine to the dynamo is converted into electricity, because a dynamo is not able to transform into current all the energy it receives. A part will always be lost in friction and in other ways. The output of the dynamo, known as the **electrical horsepower**, abbreviated E. H. P., will therefore always be less than the delivered horsepower of the engine that drives it. In order to find the brake horsepower of the engine from the electrical horsepower of the dynamo, the losses in the dynamo must be known; that is, the efficiency of the dynamo must be known. This point will be explained later.

9. Gas-Engine Indicator.—In making a test of a gas engine, it is usually desirable to determine the power exerted on the piston by the explosion and expansion of the charge. This power is measured by means of an instrument known as an **indicator,** shown at *i,* Fig. 1. The indicator used on gas engines is very similar to that used on ordinary steam engines; in fact, the same indicator is often used for both, with auxiliary attachments to adapt it to the gas engine. The piston and other moving parts of a gas-engine indicator should, however, be as light as possible, consistent with strength, in order to prevent distortion of the diagram by inertia effects.

The purpose of the indicator is to determine the pressures in the engine cylinder at all points of the stroke, and to record these pressures in the form of a diagram on a paper or a card. In the case of the gas engine, an indicator diagram may be used to determine the correct setting of the valves and the timing of ignition, as well as to find the mean pressure in the cylinder for power determinations. In order to obtain accurate results with an indicator, careful and intelligent manipulation is as essential as a well-designed instrument.

10. The general appearance of an indicator is shown in Fig. 5. The instrument consists essentially of a cylinder *a*

containing a piston and a helical spring for measuring the pressure, the lever *b* for transmitting the motion of the piston to a pencil point *c*, and the drum *d* that carries the paper or card on which the diagram of the motion is drawn. The card *e* is held close to the drum by the clips shown at *f, f*, so that the pencil can easily trace the outline of the diagram.

A section of the same indicator is shown in Fig. 6. The piston *g* is made to work in the cylinder as nearly frictionless as

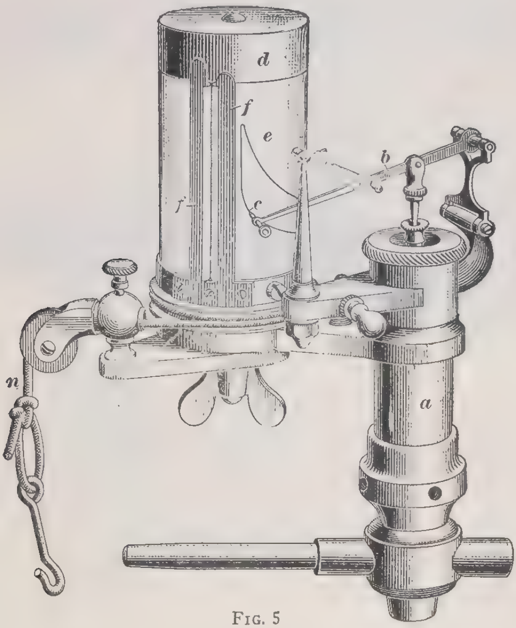


FIG. 5

possible, the spring *h* being the only resistance to its upward motion. The piston of a gas-engine indicator is given an area of .25 square inch, which is just one-half the area of the piston of a steam-engine indicator. The spring is calibrated, that is, tested, so as to determine the pressures required to move the pencil *c* to various heights against the resistance of the spring.

11. The pressure, in pounds per square inch, that is required to compress the indicator spring sufficiently to cause the pencil to be moved up 1 inch is called the **scale of the**

spring. It is, therefore, possible to find the pressure in the cylinder by the position of the pencil point when the scale of the spring is known. By turning a small cock, shown at *n*, Fig. 1, in the pipe connecting the indicator to the engine cylinder, the gas pressure in the engine cylinder may, at pleasure, be admitted to or shut off from the indicator. When the gas pressure is admitted through the channel *s*, Fig. 6, it causes the piston *g* to rise. The helical spring *h* is compressed and resists

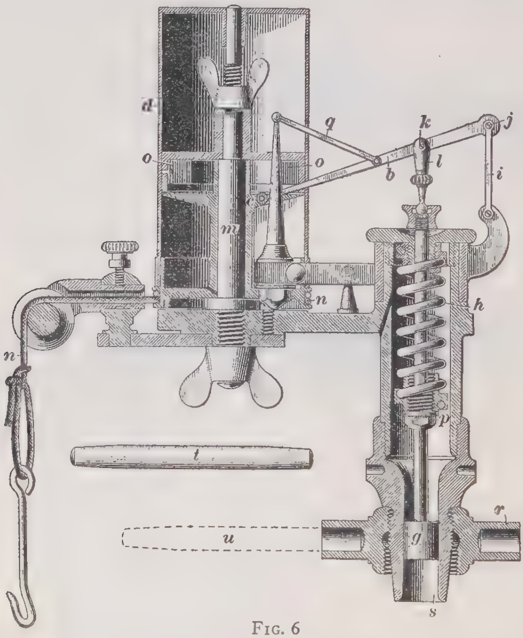


FIG. 6

the upward movement of the piston. The height to which the piston rises should then indicate correctly the pressure in the engine cylinder; and as this pressure rises and falls, the piston *g* must rise and fall accordingly.

12. To register the engine-cylinder pressure, a pencil might simply be attached to the end of the piston rod, and the point of the pencil made to press against a piece of paper. It is desirable, however, to restrict the maximum travel of the piston to about ½ inch, while the height of the diagram may

advantageously be from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches. To give a long range to the pencil while keeping the travel of the piston short, the pencil is attached at *c*, Fig. 6, to the long end of the lever *b*. The fulcrum of the lever is at *j*, and the piston rod is connected to it at *k*, through the link *l*. The pencil motion is thus much greater than the travel of the piston *g*; for most indicators, it is four, five, or six times as great. The point *c* is made to move in a vertical straight line by the arrangement of the links *i*, *l*, and *q*.

13. The indicator, however, must not only register pressures, but it must also register them in relation to the position of the piston. This registering is accomplished by means of the cylindrical drum shown at *d*, Figs. 5 and 6. The drum can be revolved on its axis *m* by pulling the cord *n* that is coiled around it. When the pull is released, the spring *o*, Fig. 6, turns the drum back to its original position. If the cord *n* is attached to some part of the engine that has a motion proportional to the motion of the piston, the motion of the drum must also be proportional to the motion of the piston. If the cord were attached directly to the piston or to some part having the same motion as the piston, the drum *d* would have to be so large that it would be cumbersome and the diagram correspondingly long and difficult to handle. For these reasons, the drum is made small and a device is employed for reducing the motion of the drum so as to give a convenient length of the diagram. This device, called a *reducing motion*, will be explained later.

The indicator shown can also be used in taking diagrams from a steam engine or any other engine in which the pressure is not so great as in the gas engine. In order to do this, the piston *g* and its rod are unscrewed at *p* and a piston that just fits the cylinder at *p* is attached. The area of the cylinder at this point is just twice that of the piston *g*; hence, only one-half as much pressure per square inch will be required to produce the same pencil movement.

14. To attach the indicator to the engine, a hole is drilled in the cylinder head into the clearance space of the engine and tapped for a $\frac{1}{2}$-inch pipe, as shown in Fig. 1, with an

elbow turned up and carrying a nipple and a valve *n* next to the indicator. The lower end *s*, Fig. 6, is inserted in the fitting attached to the valve and the connection *r* is tightened by means of the handle *t* shown dotted at *u*. When the indicator is to be used, a card or a piece of blank paper of convenient size is placed around the drum, with the ends of the paper projecting from behind the clips through the space between them. The drum revolves with a motion proportional to the stroke of the engine, and consequently to the volume swept through by the piston, and the pencil moves up and down with a motion proportional to the pressure in the cylinder. Hence, when the pencil is held against the paper, it draws a diagram of pressures and volumes, recording these two quantities in such a way that they can be measured for every point of the stroke.

15. Manufacturers of indicators usually supply a special paper for use on the indicator, known as *metallic paper,* which is made by coating ordinary paper with a special preparation that will turn black when rubbed with a brass wire. The indicator pencil may then be replaced by a piece of ordinary brass spring wire, and the trouble of keeping a pencil sharp is obviated. Although the preparation of this paper is usually considered a secret, a coating of zinc oxide, known also as zinc white or Chinese white, will answer the same purpose. The zinc oxide is mixed with some gum solution or glue, and spread evenly over the surface of the paper. The paper is then allowed to dry, and is afterwards subjected to pressure for a day or two to remove the tendency to curl. The surface should be smooth and free from lumps or ridges, as these will cause unnecessary friction. Diagrams made on metallic paper are usually much more distinct than those made with a pencil.

16. The indicator spring to be chosen depends entirely on the initial pressure in the cylinder. The scale of the spring should be such as to give not over $1\frac{3}{4}$ inches vertical movement to the pencil for the highest pressure obtained in the cylinder. For instance, if the initial pressure is 175 pounds, a 100-pound or 120-pound spring should be chosen; that is, the

scale of the spring should be either 100 or 120 pounds. The scale of the spring (100 pounds) indicates that the pencil will move 1 inch for each 100 pounds pressure per square inch on the piston. In general, it is advisable to select a spring that will give a diagram between $1\frac{1}{2}$ and $1\frac{3}{4}$ inches high. A diagram less than $1\frac{1}{2}$ inches in height is objectionable, for it is too small to show properly the valve setting; hence, in such cases, it is advisable to use a spring of lower scale. The indicator is sometimes provided with a safety stop, so that the piston will not rise too high and thus cause damage to the spring and other moving parts.

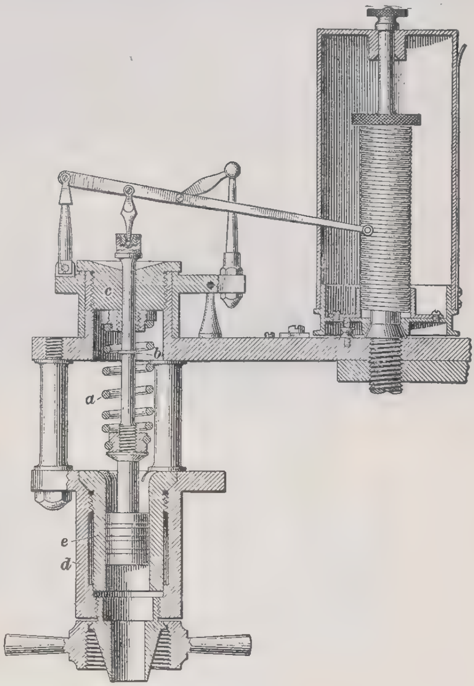


Fig. 7

The cylinder of the indicator *i*, Fig. 1, is connected to the compression space by $\frac{1}{2}$-inch gas pipe, as shown, a plug cock *n* being inserted between the engine and the indicator. A bunch of waste saturated with water should be tied around the indicator at *o* and kept wet constantly, in order to prevent damage to the indicator from overheating.

17. In the form of indicator just described, the spring is contained in the barrel in which the piston works and is apt to be affected to some extent by the temperature of the gases. To obviate this difficulty, the **outside-spring indicator** has been developed. A sectional view of such an instrument is shown

in Fig. 7. The construction is similar in many respects to that of the indicator shown in Fig. 6, but in the form shown in Fig. 7 the spring *a* is wholly outside the barrel containing the piston. As a result, the spring is subjected at all times to atmospheric temperature and does not become heated as in the case of the inside-spring type. It will be observed that a collar *b* is formed on the piston rod. The purpose of this collar is to prevent overcompression of the spring and damage to the pencil motion. If the pressure developed in the cylinder should be considerably higher than is expected, the spring will be compressed until the collar strikes the under side of the cap *c*, which will prevent further upward movement of the piston rod or the pencil motion. The barrel *d* is made with a removable liner *e* that permits the size of cylinder and piston to be changed for low-pressure work. The illustration shows the piston of small diameter used in taking indicator diagrams from gas engines. This piston usually has an area of $\frac{1}{4}$ square inch, whereas that used in steam-engine work, in which the pressures are not so great, has an area of $\frac{1}{2}$ square inch.

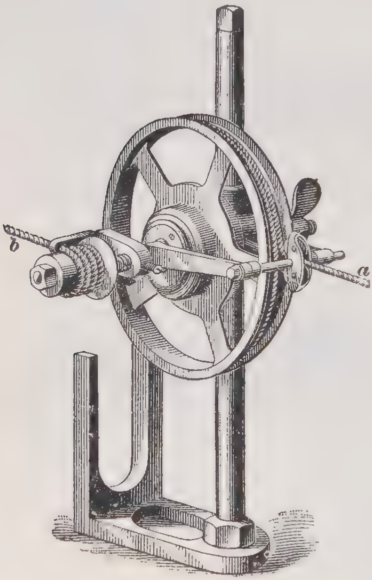


Fig. 8

18. Reducing Motions. — There are many devices, known as **reducing motions,** for reducing the motion of the engine piston to one suitable for the indicator drum. The **reducing wheel** *r*, Fig. 1, is perhaps the most convenient for general use. It is shown on a larger scale in Fig. 8; the cord *a* is attached to a rod on the piston, and the cord *b* is attached to the indicator drum. The other end of the cord *a* is attached to

the large wheel and wound several times around it. As the cord *a* is pulled by the piston, it unwinds, turning the large wheel and the small wheel at the same time. The spindle of the small wheel has a screw thread of a pitch equal to the thickness of the cord, so that the arms of the cord guides, which are held from turning about the spindle, are moved, with each revolution, along the spindle a distance equal to the thickness of the cord. Hence, the cords never wind over themselves, but each cord is laid up in a continuous coil on the pulley as the other unwinds from its pulley. The pulleys being fastened together, the smaller turns with the larger; and, as the cord *a* unwinds one turn from the large pulley, the cord *b* unwinds from the indicator drum and winds one turn on the smaller pulley. Hence, the motion of the two cords is proportional to the circumferences or diameters of the two pulleys.

The smaller pulley can be removed and replaced by one of several others of different sizes. The proportions of the two pulleys should be such that the length of the diagram will be between $2\frac{1}{2}$ and $3\frac{1}{2}$ inches. Thus, if the stroke of the engine is 12 inches, and the desired length of the diagram is 3 inches, the diameter of the larger pulley should be four times that of the smaller.

19. The small sketch at the right of Fig. 1 illustrates the method of connecting the cord from the reducing wheel to the engine piston. A $\frac{1}{4}$-inch iron rod *l* is bent at right angles, as shown, and attached to the inside of the piston by two or three small machine screws. The end attached to the piston should, of course, be drawn out flat before the holes for the screws are drilled. A hook is made at *m*, to which the cord from the reducing wheel is to be attached. The wheel can be placed at any convenient point between the point *m* and the indicator.

20. Reducing motions that employ gears are frequently used. Such a reducing motion is shown in Fig. 9, attached to an indicator. This motion really consists of two wheels; on the larger one, shown at *a*, is wound the cord that is attached to the rod on the piston, and from the smaller one *b* runs the

cord to the indicator drum. A spring in the horizontal case *c* acts on the pulley *a* through the bevel gears, resisting the pull of the piston on the string, on its outward stroke, and drawing in the string on the return stroke, thus always keeping the string tight. In the same way, the spring in the indicator drum *d* keeps the string tight between the drum and the pulley *b*.

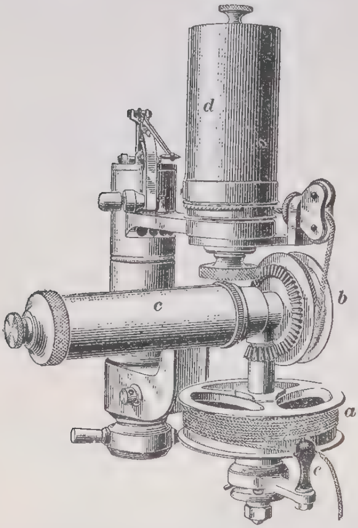


Fig. 9

21. Very often the reducing wheel is attached directly to the body of the indicator, as shown in Fig. 9, thus avoiding the necessity of fastening it to the engine, as shown in Fig. 1. When the reducing wheel is attached directly to the indicator, the cord from the wheel *b*, Fig. 9, to the indicator drum *d* is short and direct, making a connection with very little lost motion.

The wheel *a* is very easily detached from the mechanism, and is one of several different sizes that are furnished with the apparatus, to be used on engines of different lengths of stroke. The cord guide *e* is arranged so that it can be turned to any position in its horizontal plane and fastened there, when it has only the vertical motion necessary to lay the cord on the wheel uniformly.

Fig. 10

22. There should be some means arranged to stop the motion of the drum when not in use. This is easily done by dividing the cord from the indicator drum to the reducing wheel, and connecting the two portions by means of a loop *l* and a hook *a*, Fig. 10. The knots should be so tied that they will not slip. The small piece of

wood *b* makes a very neat arrangement about which to make the loop, as the cord will not slip and is easily untied, and the length of cord is readily adjusted. In case the reducing wheel is connected to the indicator, as shown in Fig. 9, the hook is placed in the cord running from the reducing wheel to the rod on the piston.

23. Gas Measurement.—The gas that is supplied to the engine should be measured by a proving meter connected as shown at *x*, Fig. 1. Such a meter has a large dial and gives the number of cubic feet per hour from an observation of 1 minute, as well as the total gas consumption over any period of time. The gas from the meter should pass to the engine through an india-rubber gas bag *y*, or some other form of pressure equalizer. In gasoline- or oil-engine tests, the fuel must be weighed.

24. When it is necessary to measure the heat wastes and calculate the ratio each bears to the heat supplied, the heating value of the gas should be obtained. Quite frequently, the gas company has a record of the average heating value of the gas it manufactures. If it has no such record, a sample of the gas should be sent to a laboratory to be properly tested for this value. This determination is absolutely essential to a complete test, or for a comparison of engines tested with different grades of gas.

25. Cooling-Water Tanks.—In order to ascertain the amount of heat carried off by the jacket water, it is necessary to know the weight of water that passes through the jacket and the rise of temperature caused by the heat of the engine. The weight of water may be measured in one of two ways: the water may be weighed directly, by means of a platform scale, using a tank or a barrel set on the scale platform; or, if the scale is not convenient, the volume may be measured and the weight calculated. Since a certain volume of pure water at the same temperature always has the same weight, it is a simple matter to measure the water directly in pounds. For this purpose, the measuring tank *q*, Fig. 1, is so constructed that the depth of the water, in inches, gives its weight, in

hundreds of pounds, when multiplied by 2. The tank is made of plank, and measures $37\frac{1}{2}$ in.$\times 37\frac{1}{2}$ in. inside dimensions. The height may be from 2 to 3 feet, as found most convenient. The stick *s* is marked off in inches or $\frac{1}{2}$ inches as desired. This is used for measuring the depth of water in the tank. When the bottom of the tank is level, each 2 inches in depth indicates 100 pounds of water, and each $\frac{1}{2}$ inch 25 pounds of water. If the stick is marked off in tenths of an inch, each tenth will indicate 5 pounds of water. These dimensions are computed for water at a temperature of 110° F. If a smaller tank or more accurate measurement is required, a tank $26\frac{1}{2}$ in.$\times 26\frac{1}{2}$ in. will give 25 pounds for each inch on the stick, 100 pounds for each 4 inches, and 5 pounds for each $\frac{1}{5}$ inch.

When the quantity of water used is small, or when very accurate determinations are to be made, the water should be weighed. This can be done quite readily by using two receptacles and changing them at the moment of taking the reading. For instance, if the reading is taken every 5 minutes, the stream should be changed from one to the other, just as the signal is given.

26. Thermometers.—In tests of gas and oil engines, thermometers are used to measure the temperatures of the gas, cooling water, oil, atmosphere, etc. These thermometers should be of the kind having the graduations marked directly on the glass stem. For accurate tests, they should be calibrated; that is, the amount of error at the various temperatures recorded by the thermometer should be known. Since thermometers are so easily broken, it is advisable, in important tests, to have a few extra ones on hand, so that an accidental breakage will not interrupt the taking of readings and thereby spoil the test. Extra thermometers should be calibrated. If mercury thermometers are used to determine the exhaust-gas temperature, or any temperature above about 500° F., they should be of the kind having nitrogen in the top of the tube and having a safety bulb at the top. Such thermometers can be used for temperatures as high as 1,000° F. In Fig. 1, the temperature of the entering water is taken by a thermometer

at t, and that of the discharge at t'. The thermometers are not directly in contact with the water, but are inserted in small cups containing oil. The temperature of the room is taken by the thermometer t_1.

27. Pyrometer.—The temperature of the exhaust gases must be taken in order to determine the loss of heat by way of the exhaust pipe. For this purpose a form of temperature indicator known as a **pyrometer** is generally used. One form of pyrometer is shown in Fig. 11. The stem *s* is composed of two tubes made from metals having different rates of expansion. The metals generally used are copper and iron, the copper tube being placed inside the iron tube, or vice versa. The entire stem from the nut *k* should be subject to the temperature it is desired to measure. Since the outside tube is heated first, the pointer frequently moves rapidly forwards or backwards around the dial. As soon as the stem is thoroughly heated, the pointer will indicate the temperature of the gases. A pyrometer is also shown at *p*, Fig. 1.

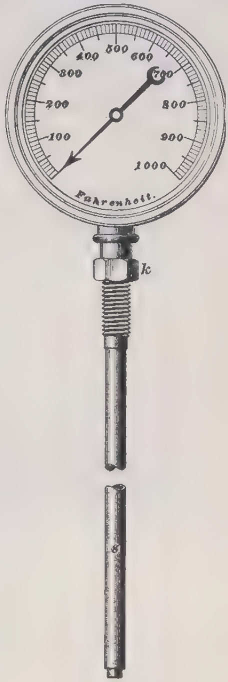


FIG. 11

28. Revolution Counter.—The engineer should be provided with one of the three forms of revolution counters shown in Figs. 12, 13, and 14. That in Fig. 12 is a *continuous counter;* that in Fig. 13, a *speed indicator;* and that in Fig. 14, a *tachometer*.

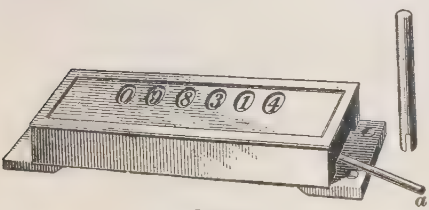


FIG. 12

The arm *a* of the **revolution counter,** shown in Fig. 12, is attached to some reciprocating part of the engine. The number of revolutions per minute may be deter-

mined by means of a watch, and the number registered at the beginning and end of a minute noted. The difference between the second and the first reading will be the number of revolutions per minute. The readings of the counter may, instead, be noted at regular intervals (say of 10 minutes each), and the total number of revolutions registered during that time divided by the number of minutes; the result will be the number of revolutions per minute.

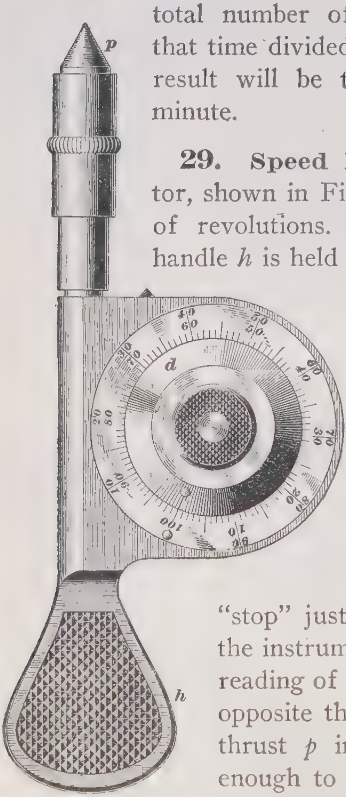


FIG. 13

29. Speed Indicator.—The speed indicator, shown in Fig. 13, registers the total number of revolutions. It is used as follows: The handle *h* is held in the hand, and the soft rubber point *p* is thrust into the center countersink on the end of the crank-shaft; the dial *d* will then register the number of revolutions. The best way to use this instrument is to have an assistant observe the time. He should give the signal "go" at the beginning of the minute, and the signal "stop" just as the minute is up. First, set the instrument at zero, or carefully note the reading of the dial. Then, hold the point *p* opposite the center, and at the signal "go" thrust *p* into the center, holding it tight enough to prevent it from slipping. Note the number of revolutions of the dial, and at the signal "stop" immediately draw the indicator away from the shaft. As the dial reads to 100, each revolution of the dial will mean 100 revolutions of the crank-shaft. Thus, if the dial makes two turns and the pointer stops at 50, the number of revolutions is 250.

30. Tachometer.—The **tachometer,** which is shown in Fig. 14, is an instrument for measuring the number of revolu-

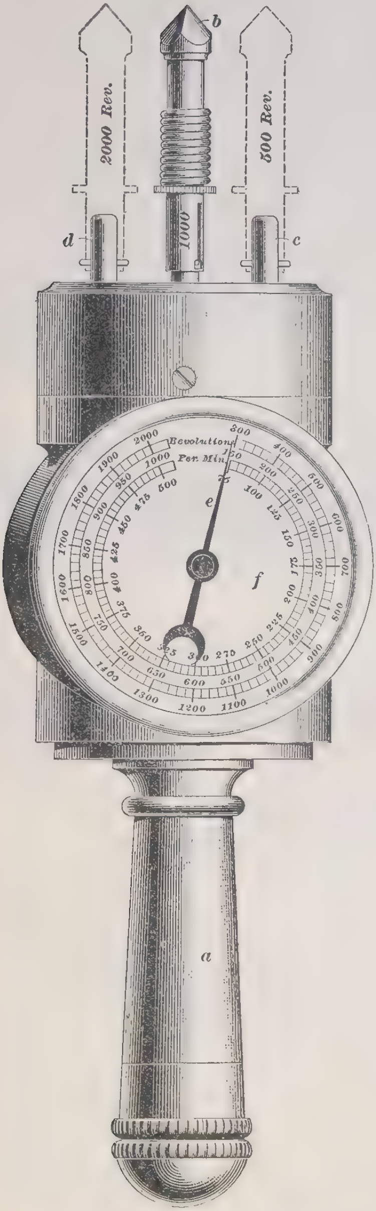


FIG. 14

tions of a shaft per minute. In principle, it is a small centrifugal machine, somewhat like the flyball engine governor. The handle *a* is held in the hand, and the pointer *b* is pressed into the center mark of the shaft. The pointer is removable and can be placed on the spindles *c* or *d*, as shown by the dotted lines, depending on the speed of the shaft. The spindle *c* is to be used for speeds less than 500 revolutions per minute; *b*, for speeds between 500 and 1,000 revolutions per minute; and *d*, for speeds between 1,000 and 2,000 revolutions per minute. The pointer *e* is moved around the dial *f* by the movement of the weights, according to the speed at which they are driven. The instruments are usually made with three scales, and it is necessary to read the number of revolutions on the scale corresponding to the spindle used. The axis of the instrument must be kept parallel with the shaft, and the spindle used must be in exact line with the axis of the shaft, or the vibration of the pointer will prevent accurate observation.

CONDUCTING THE TEST

GENERAL INSTRUCTIONS

31. Before the test of a gas or oil engine is begun, all parts of the apparatus should be thoroughly examined, and their condition should be noted on the records. At the same time, the various dimensions, such as diameter of cylinder, stroke, clearance volume, etc., can be found and noted, if these data cannot be obtained from accurate working drawings. If the object of the test is to find the highest efficiency or the greatest capacity of the engine, the entire apparatus should be cleaned, overhauled, and put in the best possible running condition; but if, on the other hand, the object is to determine the performance of the engine under existing conditions, no such overhauling need be done. If the results of the test are to be used in determining whether the engine fulfils contract guarantees, there should be a written agreement between both parties as to the conditions of operation during the test, the methods of testing to be followed, the corrections to be made in case the actual conditions during the test differ from those specified, and all other points on which there may be a chance for dispute.

32. The length of a test of an engine running under a practically uniform load should be sufficient to give a number of successive records covering intervals of half an hour or less, during which the results are found to be uniform. For all practical purposes, from 3 to 5 hours is sufficient. If the load varies considerably, the length of the test should be increased so as to secure average results for the conditions under which the engine is operating. The length must depend upon the judgment of the engineer after he has carefully observed the working conditions. The length and number of observations will depend on the results sought. To start the test, the engine is set to work under the desired conditions, and at a given signal the records are begun by weighing the oil and noting the

weight, taking the temperatures, measuring the power, and so on. These observations are continued at regular intervals until the end of the test. It is important in order to prepare an accurate report of a test of a gas engine to keep a careful record of all the elements that enter into the test. When the stopping time arrives the test is closed by simply taking the final readings.

METHOD OF MAKING THE TEST

33. The number of assistants required when making a gas-engine test depends entirely on the number and frequency of the readings to be taken. One man should watch the brake and keep the load constant by adjusting the nut *e*, Fig. 1; another should take indicator diagrams and note the speed; while a third should weigh or measure the water, note the temperatures, and read the meter. This last may sometimes be divided between two observers, making four in all. In special cases, one man could take indicator diagrams and all readings; but such an arrangement is not a good one, because all the readings should, if possible, be taken at the same instant. With two observers, readings should be taken every 10 minutes. With three or four observers, readings may be taken every 5 minutes.

34. It is best to make several separate runs, each with a different load on the brake. Twelve or more readings should be taken with each load, so that, if readings are taken every 5 minutes, the run will last 1 hour, while with a 10-minute interval, it will last 2 hours. At least three runs should be made: one at full load, another at half load, and a third at no load. If the engine is a large one, several runs should be made at other loads, in order that the economy of the engine under these various conditions may be ascertained. It is also advisable to know the maximum load the engine is capable of carrying. The sensitiveness of the governor should be determined, where possible, by noting any change of speed when passing suddenly from full load to no load.

LOG OF TEST

*Gas Engine*________________ *Made by*________________

*At*________________ *19*___

Number	Time	Revolutions per Minute	Explosions per Minute	Temperature of Room Degrees Fahrenheit	Temperature of Exhaust Degrees Fahrenheit	Jacket Water			Dynamometer			Gas		Mean Effective Pressure	Indicated Horsepower	Brake Horsepower
						Temperature of Injection Degrees Fahrenheit	Temperature of Discharge Degrees Fahrenheit	Weight Pounds	Scale Reading Pounds	Net Pressure Pounds	Foot-Pounds per Revolution	Cubic Feet	Pressure Inches of Water			
1																
2																
3																
4																
5																
6																
7																

35. The person in charge should be provided with a whistle. Thirty seconds before the time for taking the readings, he should blow two blasts on the whistle, when every observer should at once go to his post. At the moment for taking the readings, one blast should be blown, and all readings must, as far as possible, commence at the signal. No looker-on should be allowed to interfere with the observers, and no observer should rely on any one else, particularly an outsider, to take or record the observations allotted to him.

36. Before beginning a trial of any kind, the one in charge should see that a sheet is prepared for recording the data observed while the trial is in progress. This sheet—called the *log*—should be ruled in horizontal lines and vertical columns, and each column should be headed with an explanatory phrase or note, showing what particular record is to be placed in that column. Keeping notes on loose sheets of paper is bad practice. The accompanying Log of Test is a very convenient form for the purpose. There should be lines enough for recording at least fifteen sets of observations. Only such observations as are taken during the test, together with the individual results from each reading, should be entered on the log.

REPORT OF THE TEST

37. After the first test is made and the data are obtained, the report should be written. A convenient form for the report is shown on the next page.

The space before the words *gas engine* should be filled in with the maker's name, and *made by* should be followed by the name of the person or engineering firm that made the test and is responsible for the accuracy of the results. The next line should contain the name of the locality where the test was made, followed by the date.

The report should be made out in duplicate, one copy being kept by the party that makes the test and the other being given to the party for whom the test is made.

38. Clearance.—The first three dimensions in the report blank are obtained by actual measurement, and need no expla-

nation. The **piston displacement** is the product of the area and the stroke of the piston, and is usually expressed in cubic feet. The **clearance** is measured most readily in the

REPORT OF TEST

________________________________ *Gas Engine*

Made by ________________________________

At ________________________________ *19*__

DIMENSIONS OF ENGINE		Air—weight of cubic foot....Lb.	
Diameter of piston..........In.		Mixture—weight of cubic foot.Lb.	
Area of piston............Sq. in.		Specific heat, gas...............	
Length of stroke............Ft.		Specific heat, air...............	
Piston displacement ......Cu. ft.		Specific heat, mixture...........	
Clearance ....Cu. ft.		Heat value cu. ft. gas....B. T. U.	
Clearance ....Per cent.		RESULTS	
DATA		Work—ft.-lb. per min...Average	
Duration trial ....Hr.		Work—ft.-lb. per hour..Average	
Gas per hour ....Cu. ft.		B. H. P. ....Average	
Air per hour ....Cu. ft.		Indicated M. E. P. ......Average	
Ratio, gas to air		Indicated H. P. ....Average	
Jacket water per hour........Lb.		Gas per I. H. P. ....Cu. ft.	
Jacket-water temperature, inlet, ... °F.		Gas per B. H. P. ....Cu. ft.	
Jacket-water temperature, outlet .... °F.		Mech. eff. B. H. P. ÷ I. H. P.	
Jacket-water temperature, range .... °F.		Friction loss I. H. P. − B. H. P.	
Revolutions per minute..Average		HEAT PER HOUR	
Revolutions per hour............		Supplied by gas..........B. T. U.	
Explosions per minute...Average		Absorbed by jacket water ....B. T. U.	
Explosions per hour.............		Exhausted ....B. T. U.	
Temperature of exhaust......°F.		Absorbed in work......B. T. U.	
Temperature of room........°F.		Radiation ....B. T. U.	
Length of lever arm..........Ft.			
Brake load, average.........Lb.		Thermal efficiency ......Per cent.	
Gas—weight of cubic foot....Lb.		B. T. U. per I. H. P............	

following manner: Place the crank on the inner dead center, and close every opening but one, which should be on top. Then weigh a bucketful of cold water, and pour it through a funnel into the compression space, taking care that none is spilled and

that the compression space is just full and no more. Weigh the water that remains in the bucket, and subtract this amount from the first weight. Divide the remainder by 62.5, and the result will be the clearance, in cubic feet.

Let C = clearance, in cubic feet;
W = first weight, in pounds;
w = second weight, in pounds.

Then, $$C=\frac{W-w}{62.5}$$

In the larger engines, more than one bucket of water may be required, and W should then be taken as the sum of the weights of the full buckets, and w the sum of the weights of the buckets from which the water has been poured.

The *percentage of clearance* is found by dividing the clearance volume by the piston displacement.

EXAMPLE.—The diameter of an engine cylinder is 10 inches, and the length of the stroke is 12 inches. A bucket of water is found to weigh 21 pounds, and after filling the compression space the bucket and remaining water weigh 9.5 pounds. What is: (*a*) the piston displacement, in cubic feet? (*b*) the clearance, in cubic feet? (*c*) the percentage of clearance?

SOLUTION.—(*a*) The piston displacement is

$$\text{area}\times\text{stroke}=.7854\times 10^2\times 12=942.48 \text{ cu. in.}$$
$$=942.48\div 1{,}728=.5454+ \text{ cu. ft. Ans.}$$

(*b*) By substituting in the formula,

$$C=\frac{W-w}{62.5}=\frac{21-9.5}{62.5}=.184 \text{ cu. ft. Ans.}$$

(*c*) By dividing the clearance by the piston displacement, the percentage of clearance is found to be

$$.184\div .5454=.337, \text{ or } 33.7 \text{ per cent. Ans.}$$

39. Volume of Air Used.—The air used per hour may be found, roughly, by deducting the amount of gas used *per explosion* from the piston displacement, and multiplying this quantity by the number of explosions per hour.

Let P = piston displacement, in cubic feet;
G = cubic feet of gas per explosion;
E = number of explosions per hour;
A = cubic feet of air used per hour.

Then, $$A=(P-G)\,E$$

EXAMPLE.—A gas engine has a piston displacement of .5 cubic foot, and the amount of gas used per explosion is .05 cubic foot; when exploding 5,000 times per hour, how many cubic feet of air is used per hour?

SOLUTION.—By substituting in the formula,

$$A=(P-G)E=(.5-.05)\ 5{,}000=.45\times 5{,}000=2{,}250 \text{ cu. ft.} \quad \text{Ans.}$$

While this method for finding the volume of air taken into the engine is frequently used, it is better to measure the air by means of a meter. The ratio of the gas to the air is the ratio of the quantity of gas supplied per hour to the quantity of air used in the same time. Thus, if 50 cubic feet of gas is used per hour, and 400 cubic feet of air is used in the same time, the ratio of gas to air will be 50 : 400, or 1 : 8.

40. Measurement of Gas Pressure.—Since the pressures dealt with in gas supply and distribution are quite small, it is the custom to use a unit of measurement of pressure smaller than the pound per square inch. The universally adopted unit is the pressure per square inch exerted at its base by a column of water 1 inch high, which is .03617 pound. For the sake of brevity and convenience, the pressure is not reduced to pounds, but is expressed by simply stating the height of the water column, in inches, that the pressure will balance. Thus, if there is a pressure in a gas main sufficient to balance a column of water $4\frac{1}{2}$ inches high, the pressure is said to equal, or to be, $4\frac{1}{2}$ inches of water. Ordinarily, the pressure of the gas is measured directly by attaching a water gauge, or **U** gauge, to the gas main and reading the pressure in inches of water from the graduated scale.

41. Gas Consumption. — Comparisons with other engines should always be made as nearly as possible under the same conditions. A gas engine will lose more heat by radiation in a cold room than in a hot one, and a considerable difference in gas consumption will be noted when working with cold or with hot jacket water.

For the comparison of engines working with different kinds of gas, the heat value of the gas used, in British thermal units, is a much better basis than the gas consumption; for a gas

engine that will need 20 cubic feet of city gas to develop 1 horsepower may require 80 cubic feet of producer gas per horsepower; or the same engine may develop 1 horsepower on 10 or 12 cubic feet of natural gas. If, however, the gas for the several engines to be tested should be taken from the same source, a comparison of the gas consumption per horsepower will be sufficient.

42. Temperatures.—A double purpose is served by taking the temperature of the water as it enters and as it leaves the jacket. The first is that the operator is thereby enabled to keep the temperature fairly uniform during the trial; and the second, that the water acts as a factor in the measurement of the loss of heat through the jacket. This loss of heat is, of course, not altogether the fault of the engine itself, for much depends on the way the flow of water is controlled. The best makers advise the use of a circulating tank, in which the water soon reaches the boiling point. and which reduces to a minimum the amount of heat carried away.

The determination of the exhaust temperature is not so important in a partial test as the determination of the jacket-water temperature, but it serves as a check on the indicator diagram.

43. The temperature of the room should be subtracted from the exhaust temperature in calculating the loss through the exhaust; for the temperature of the gas and air entering the engine cylinder is approximately the same as that of the room, and the heat thus carried into the engine must be deducted from the heat in the exhaust, in order to determine the amount of heat due to combustion that is lost in the exhaust. The temperature of the room will give some idea as to the loss due to radiation from the engine. An exceedingly high temperature indicates a large amount of radiation; while a normal temperature indicates but slight radiation loss. The specific heats of the gas, the air, and the mixture will be treated under Heat Losses, while the thermal and mechanical efficiencies will be taken up in connection with the subject of efficiency.

TABLE I

DATA AND RESULTS OF GAS- OR OIL-ENGINE TEST

(1) Test of...............engine, located at....................
To determine ....
Test conducted by...

DIMENSIONS, ETC.

(2) Type of engine, whether oil or gas............................
(3) Class of engine (mill, marine, motor for vehicle, etc.)...........
(a) Number of strokes of piston for one cycle, and class of cycle......
(b) Method of ignition..
(c) Single or double acting.....................................
(d) Arrangement of cylinders....................................
(e) Vertical or horizontal......................................
(4) Rated power ....H. P.
(a) Name of builder...
(5) Number and diameter of working cylinders..................in.
(a) Number and diameter of compression cylinders................in.
(b) Diameter of piston rods.....................................in.
(6) Stroke of pistons.......................................ft.
(a) Compression space referred to piston displacement.........per cent.
(b) Stroke of compression piston................................ft.
(c) H. P. constant for 1 lb. M. E. P. and 1 R. P. M.............H. P.

DATE, DURATION, ETC.

(7) Date ....
(8) Duration ....hr.
(9) Kind of oil or gas.......................................
(a) Physical properties of oil (specific gravity, burning point, flashing point)..

AVERAGE PRESSURE AND TEMPERATURE

(10) Pressure of gas near meter......................in. of mercury
(a) Barometric pressure.............................in. of mercury
(11) Temperature of gas near meter........................deg. F.
(a) Temperature of cooling water, inlet.......................deg. F.
(b) Temperature of cooling water, outlet......................deg. F.
(c) Temperature of air by dry-bulb thermometer................deg. F.
(d) Temperature of air by wet-bulb thermometer................deg. F.
(e) Temperature of exhaust gases at cylinder..................deg. F.

TOTAL QUANTITIES

(12) Gas or oil consumed.................................cu. ft., lb.
(13) Moisture in gas, in per cent. by weight, referred to dry gas ....per cent.
(14) Equivalent dry gas at 60 deg. F. and 30 in.................cu. ft.
(a) Air supplied..cu. ft.
(15) Cooling water supplied to jackets............................lb.
(a) Water or steam fed to cylinder..............................lb.

TABLE I—(*Continued*)

(16) Calorific value of oil per lb., or of dry gas per cu. ft., at 60 deg. F. and 30 in. by calorimeter test (higher value) . B. T. U.

HOURLY QUANTITIES

(17) Gas or oil consumed per hour........................cu. ft., lb.
(18) Equivalent dry gas per hour at 60 deg. F. and 30 in.........cu. ft.
(19) Cooling water supplied per hour............................lb.
(20) Heat units consumed per hour (Item 16×Item 18)......B. T. U.

ANALYSIS OF OIL

(21) Carbon (C)....................................per cent.
(22) Hydrogen (H)..................................per cent.
(23) Oxygen (O)....................................per cent.
(24) Sulphur (S)...................................per cent.
 (*a*) Moisture.......................................per cent.
 (*b*) Result of fractional distillations.................................

ANALYSIS OF FUEL GAS BY VOLUME

(25) Carbon dioxide (CO_2)..............................per cent.
(26) Carbon monoxide (CO)............................per cent.
(27) Oxygen (O)....................................per cent.
(28) Hydrogen (H)..................................per cent.
(29) Marsh gas (CH_4)................................per cent.
(30) Heavy hydrocarbons (C_nH_m)........................per cent.
 (*a*) Sulphur dioxide (SO_2)................................per cent.
 (*b*) Hydrogen sulphide (H_2S)..............................per cent.
 (*c*) Nitrogen (N) by difference............................per cent.

ANALYSIS OF EXHAUST GASES BY VOLUME

(31) Carbon dioxide (CO_2)..............................per cent.
(32) Carbon monoxide (CO)............................per cent.
(33) Oxygen (O)....................................per cent.
(34) Nitrogen (N)...................................per cent.

INDICATOR DIAGRAMS

(35) Pressure above atmosphere........................lb. per sq. in.
 (*a*) Maximum pressure................................lb. per sq. in.
 (*b*) Pressure at beginning of stroke......................lb. per sq. in.
 (*c*) Pressure at end of expansion........................lb. per sq. in.
 (*d*) Exhaust pressure at lowest point....................lb. per sq. in.
(36) Mean effective pressure.........................lb. per sq. in.

SPEED

(37) Revolutions per minute..............................R. P. M.
(38) Average number of explosions or firing strokes per minute......
 (*a*) Variation of speed between no load and full load..........R. P. M.
 (*b*) Momentary fluctuation of speed on suddenly changing from full load to half load...........................R. P. M.

TABLE I—(*Continued*)

POWER

(39) Indicated horsepower ....I. H. P.
(40) Brake horsepower ....B. H. P.
(41) Friction horsepower by difference (Item 39—Item 40)*..F. H. P.
(*a*) Friction horsepower by friction diagrams................F. H. P.
(42) Percentage of indicated horsepower lost in friction
Item 41 ....per cent.

ECONOMY RESULTS

(43) Heat units consumed by engine per I. H. P. per hour†...B. T. U.
(44) Heat units consumed by engine per B. H. P.............B. T. U.
(45) Dry gas at 60 deg. F. and 30 in. consumed per
I. H. P.-hr....................................lb., cu. ft.
(46) Pounds of oil or cubic feet of dry gas per B. H. P.-hr...lb., cu. ft.

EFFICIENCY

(47) Thermal efficiency referred to indicated horsepower.....per cent.
(48) Thermal efficiency referred to brake horsepower.........per cent.

WORK DONE PER HEAT UNIT

(49) Net work per B. T. U. consumed (1,980,000÷Item 40).....ft.-lb.

HEAT BALANCE

(50) Heat balance, based on B. T. U. per I. H. P. per hour..........

	B. T. U.	*Per Cent.*
(*a*) Heat converted into work.................	2,546.5‡	....
(*b*) Heat rejected in cooling water.............	......	....
(*c*) Heat rejected in the dry exhaust gases......	......	....
(*d*) Heat lost due to moisture formed by burning of hydrogen	......	....
(*e*) Heat lost in superheating moisture in gas and air	......	....
(*f*) Heat lost by incomplete combustion.........	......	....
(*g*) Heat unaccounted for, including radiation....	......	....
(*h*) Total heat consumed for I. H. P.-hr., same as Item 43		....

SAMPLE DIAGRAMS

(51) Sample indicator diagrams from each cylinder and if possible a stop-motion light-spring diagram showing inlet and exhaust pressures ....

NOTE.—For an engine driving an electric generator, the form may be enlarged to include electrical data observed during the test.

*In two-cycle engines this includes the power required for compression.
†If these results, in the case of a gas engine, are based on the low value of the heat of combustion, that fact should be so stated.
‡The value adopted in the A. S. M. E. code for the equivalent in B. T. U. of one horsepower-hour.

44. After all the readings have been obtained, it is possible to trace the heat wastes from calculated results and to discover

the cause of any abnormal loss. Nothing but a proper interpretation of the indicator diagram will show faults in the action of valves or ignition. The wastes having been determined in a general way, the next step to consider is the calculation of the results from the data obtained. It is best to have a competent assistant to work up the results independently, the separate computations acting as a check on each other. If the two results thus obtained agree, they may generally be considered correct.

45. A. S. M. E. Code.—A committee of the American Society of Mechanical Engineers, appointed to revise and extend the codes relating to the testing of various forms of engines and other power apparatus, suggested the outline given in Table I, which is known as the Code of 1915. It will be noted that many of the items are printed in small type, and preceded by Italic letters. Such items may be omitted, if a short form of reporting the test is desired, or if the data called for should not be needed in determining the results for which the test is made. Unless otherwise stated, the various items should be the averages of the data recorded during the test, as given in the log of the test.

DETERMINATION OF TEST RESULTS

HORSEPOWER CALCULATIONS

46. To determine the brake, or delivered, horsepower, three things must be known: (*a*) the net pressure exerted at the end of the brake arm; (*b*) the length of the arm; and (*c*) the number of revolutions made by the crank-shaft in 1 minute. The work is done on the brake at the rim of the wheel to which the brake is attached. It is not convenient to weigh the resistance of the work at the rim of the wheel; hence, this is done at the end of the brake arm, at a distance l from the center of the shaft. The product of the resistance at the rim of the wheel and the radius of the wheel equals l times the

pressure weighed. The result is that the work may be considered as being absorbed at a distance l from the center of the shaft; that is, at the end of the brake arm.

47. If the brake arm were permitted to move with the pulley against a pressure equal to that exerted on the scales, it would be exerting that thrust through a distance, per minute, equal to the distance the end of the arm would traverse in that time. Now, it is evident that in one revolution the arm will describe a complete circumference, the length of which will be equal to $2\pi l$, where π has the value 3.1416 and l is the length of the lever arm in feet; and the total distance traversed in 1 minute will be equal to $2\pi l n$, where n is the number of revolutions made by the crank-shaft in 1 minute. This total distance traversed multiplied by the net pressure p gives the number of foot-pounds of work done in 1 minute; and, since the capacity to do 33,000 foot-pounds of work per minute is 1 horsepower, the formula for the brake horsepower is

$$\text{B. H. P.} = \frac{2\pi p l n}{33{,}000}$$

EXAMPLE.—What is the brake horsepower of a gas engine when the brake arm is 3 feet long, the net pressure on the scales 25 pounds, and the revolutions per minute 200?

SOLUTION.—In this example, $p=25$ lb., $l=3$ ft., and $n=200$ R. P. M.; hence, by substitution of these values in the formula,

$$\text{B. H. P.} = \frac{2\times 3.1416\times 25\times 3\times 200}{33{,}000} = 2.856 \text{ H. P.} \quad \text{Ans.}$$

48. It should be noted that, in the calculation of the horsepower according to the method given in the preceding article, the *net* pressure of the arm on the scales is used, and not the total pressure. When the Prony brake is at rest, there will be some pressure on the scales, due to the weight of the arm. It is plain that this pressure is not due to the rotation of the pulley and therefore should not be considered in determining the horsepower. Before the brake is tightened, therefore, the pressure on the scales due to the weight of the arm should be found. To do this, loosen the nut e, Fig. 1, until the brake is loose and free to move on the rim of the wheel. Then slowly lower the outer end of the arm on the stand j and take the reading of the

scales, which will be the pressure due to the weight of the arm. The *net* pressure is found by subtracting the pressure due to this weight from the total pressure recorded by the scales when the brake is tightened on the wheel and the engine is running under the conditions of the test.

49. Since, during any trial in which the same brake is used throughout, the length of the brake arm does not change, the factor $\frac{2\pi l}{33{,}000}$ is the same for all readings. Ascertain this once for all, and call it c. Then simply multiply c by $p\,n$ for each separate determination. Suppose, for example, that $l=6$ feet; then,

$$c=\frac{2\pi l}{33{,}000}=.001142$$

and

$$\text{B. H. P.}=c\,p\,n=.001142\,p\,n$$

It is generally advisable to keep the pressure p constant during a single run, in which case a new constant can be computed for each particular run, which will include p. Calling this new constant C, then

$$C=\frac{2\pi l}{33{,}000}, \text{ or } C=c\,p$$

50. In the ordinary form of Prony brake, the length of the brake arm is the distance from the center of the crankshaft to the point where the knife edge exerts its pressure on the scale. This distance is denoted by L in Fig. 1.

The lever arm of the strap or rope brake, illustrated in Fig. 2, is the distance from the center of the shaft to the center of the strap or rope. For example, if the diameter of the pulley is 36 inches and the belt is ½ inch thick, the brake arm will be $\frac{36+\frac{1}{2}}{2}=18\frac{1}{4}$ inches.

51. When a dynamo, or electrical generator, is direct-connected to a gas or oil engine to absorb the work done by the engine, the output of the generator is measured; then the engine horsepower is calculated from the electrical horsepower thus found. Two instruments, one a voltmeter and the other an ammeter, are used to measure the number of volts and

amperes of current generated by the dynamo. The readings of the voltmeter and ammeter are averaged from the data of the test, and the electrical horsepower is then found by the formula

$$H_e = \frac{v\,a}{746} \qquad (1)$$

in which H_e = electrical horsepower;
v = average number of volts;
a = average number of amperes.

As stated before, the brake horsepower of the engine is greater than the electrical horsepower of the dynamo, because of losses in the dynamo. So, to find the delivered horsepower, or brake horsepower of the engine, the efficiency of the dynamo must be known. This efficiency represents the percentage of energy received from the engine that is converted into electrical energy, and varies from about 88 per cent. with small dynamos to about 95 per cent. with large ones. The exact value for any particular machine must be determined by test. Let y represent the efficiency of the dynamo, expressed as a decimal. Then, the brake horsepower of the engine is found by the formula

$$\text{B. H. P.} = \frac{H_e}{y} = \frac{v\,a}{746\,y} \qquad (2)$$

EXAMPLE.—What is the brake horsepower of a gas engine direct-connected to a dynamo when the voltmeter shows 110 volts and the ammeter 215 amperes, if the efficiency of the dynamo is 92 per cent.?

SOLUTION.—Apply formula **2**. The efficiency is 92 per cent., which, expressed as a decimal, is .92; v=110 volts, and a=215 amperes. Substituting,

$$\text{B. H. P.} = \frac{110 \times 215}{746 \times .92} = 34.5 \text{ H. P.} \quad \text{Ans.}$$

52. Planimeter.—To compute the indicated horsepower from the indicator diagram, the average, or mean, height of the diagram must be found. The easiest and most accurate way to do this is to get the area of the diagram by means of a **planimeter,** and to divide this area by the length of the diagram. A planimeter suitable for this purpose is shown in Fig. 15. It consists of two bars a, b with a hinged joint c and a

roller *d*. At the end of the bar *b* is a weighted point *e*, which is pressed into the paper just enough to fix it in one position; the bar *b* then moves about the point *e* when the planimeter is in use. The point *f* on the arm *a* is the tracing point, which is moved over the outline of the diagram. The roller *d* has on one edge a flange, which should roll on a smooth surface; and behind the flange are graduations, giving readings in square inches and tenths of a square inch. By means of a vernier *g*, the graduations on the roller may be read to hundredths of a square inch.

53. There are a number of types of planimeters in use, differing in construction but operating in the same manner. The mode of reading may differ considerably, but complete instructions are always furnished with each instrument. The

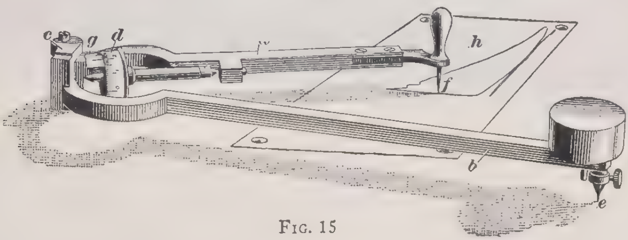


Fig. 15

planimeter should be used on a smooth level surface; a drawing board covered with a heavy well-sized paper or with bristol board answers very well. The indicator card *h*, Fig. 15, is fastened to the board, and the planimeter is set in about the position shown in the figure. The starting point is marked with the tracing point *f*, and the recording roller adjusted to zero. The outline of the diagram is then carefully traced with the point *f*, being sure to stop exactly on the starting point. The reading taken will be the area of the diagram, in square inches.

54. The area is read from the recording wheel and vernier as follows: The circumference of the wheel is divided into ten equal spaces by long lines that are consecutively numbered from 0 to 9. Each of these spaces represents an area of 1 square inch, and is subdivided into ten equal spaces, each

of which represents an area of .1 square inch. Starting with the zero line of the wheel opposite the zero line of the vernier, and moving the tracing point once around the diagram, the zero of the vernier will be opposite some point on the wheel; if it happens to be directly opposite one of the division lines on the wheel, that line gives the exact area in tenths of a square inch. The zero of the vernier, however, will probably be between two of the division lines on the wheel, in which case write down the inches and tenths that are

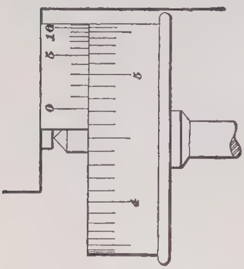


FIG. 16

to the left of the vernier zero, and from the vernier find the nearest hundredth of a square inch as follows: Find the line of the vernier that is exactly opposite one of the lines on the wheel. The number of spaces on the vernier between the vernier zero and this line is the number of hundredths of a square inch to be added to the inches and tenths read from the wheel. For example, in Fig. 16, the *o* of the vernier lies between the lines on the wheel representing 4.7 and 4.8 square inches, respectively, showing that the area is something more than 4.7 square inches. Looking along the vernier, it is seen that there are three spaces between the vernier zero and the line of the vernier that coincides with one of the lines on the wheel; this shows that .03 square inch is to be added to the 4.7 square

b FIG. 17 *a*

inches read from the wheel, making the area 4.73 square inches, to the nearest hundredth of a square inch.

55. While the form of planimeter shown in Fig. 15 is very convenient, a much simpler and less expensive instrument, called the **hatchet planimeter,** shown in Fig. 17,

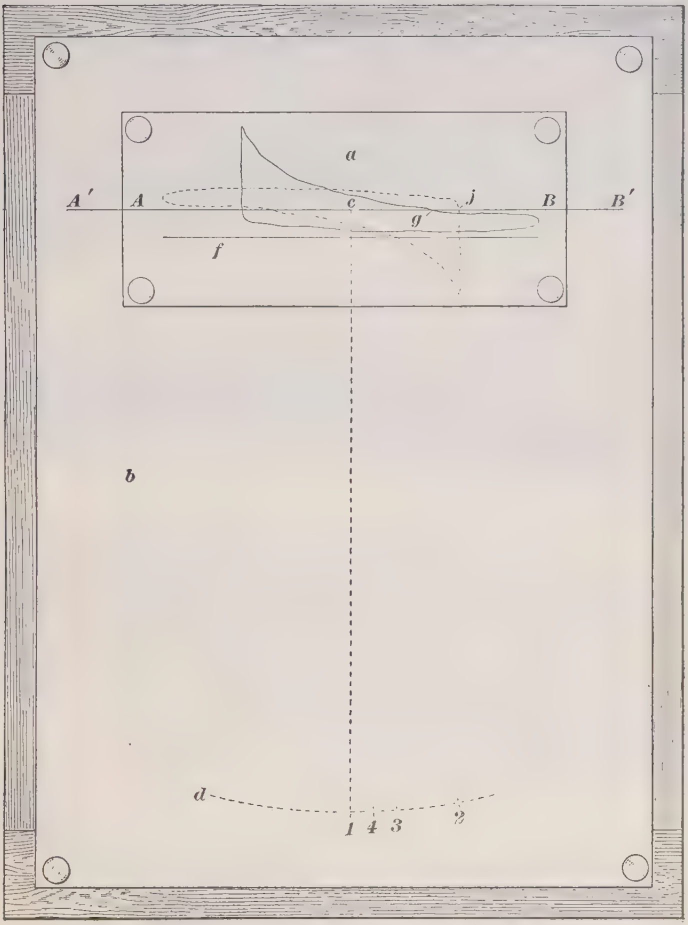


FIG. 18

may be used for measuring the areas of indicator diagrams. This simple instrument, if accurately made and used with proper care, will give very satisfactory results. It is made of $\frac{1}{4}$-inch steel rod bent at both ends, as shown. The end *a*

is sharpened for a tracing point, and the other end *b* is flattened like a hatchet and sharpened almost to a cutting edge. The edge *b* should be in line with the point *a*. The distance between the tracing point and the point at which the curved hatchet end *b* touches the paper should be at least twice the length of the indicator diagram; 10 inches is a desirable length for ordinary use.

56. The method of using the hatchet planimeter is shown in Fig. 18. The indicator card *a* is fastened to a drawing board over a piece of smooth heavy paper or bristol board *b* that is of sufficient size to furnish the surface for the records made by the hatchet. The center of gravity *c* of the diagram must be located. This may be done approximately by inspection, or it may be found quite accurately by cutting out the diagram and balancing it on the point of a pin. Draw a line *A B* through the center of gravity parallel to the atmospheric line *f*, extending it on the bristol board beyond the card *a*. With *c* as a center and the length of the planimeter as a radius, describe an arc *d* on the paper *b*. Then place the planimeter approximately at right angles to the atmospheric line *f*, and, with the tracing point at *c*, make the mark *1* on the arc *d* with the hatchet end; proceed with the tracing point from *c* to *g*, and then from *g* move it in a clockwise direction over the outline of the entire diagram, which will bring the tracing point again at *g*; now proceed from *g* to the starting point *c*. During this movement, the hatchet end is free to move on the paper *b* and takes a zigzag course across the arc *d*. The hatchet will stop at some point *2* on the arc *d*.

57. Next revolve the card 180° about the point *c*, Fig. 18, as shown by the dotted diagram, until the horizontal line *A B* coincides with the extensions *A′ B′* on the paper *b*. With the hatchet at *2* and the tracing point at *c*, move the tracing point from *c* to *j* and then around the entire diagram in a counterclockwise direction until the tracing point is again at *j*; then proceed from *j* to *c*. The hatchet will stop at some point *3* near *1*. Locate the mid-position *4* between *1* and *3* and measure the distance from *4* to *2*, using an accurately graduated

scale. A scale graduated to fiftieths or hundredths of an inch is most convenient. The area of the diagram, in square inches, will then equal the distance *4–2* multiplied by the length of the planimeter.

It is best to hold the instrument, just above the tracing point, between the thumb and forefinger, keeping the arm of the tracing point vertical and preventing the hatchet from slipping sidewise. In order that the measurement may be accurate, it is necessary that the tracing point and the arc forming the edge of the hatchet lie in the same plane, and that the distance between the points *4* and *2*, Fig. 18, and the length of the planimeter are correctly measured. It is best to locate the actual center of gravity of the diagram, although a small error

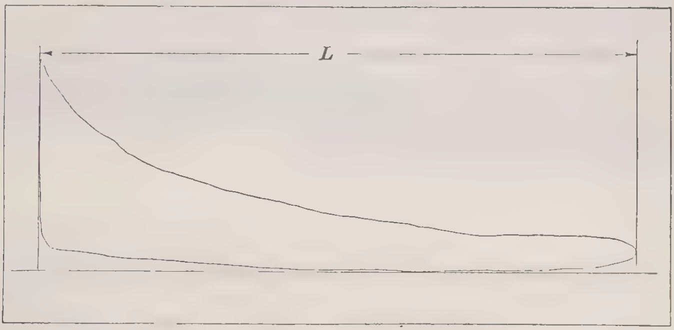


Fig. 19

in this respect will not cause serious inaccuracy, provided the planimeter is set approximately at right angles to the atmospheric line when starting.

The alinement of the hatchet with the point may be tested by drawing a straight line on a horizontal drawing board, and then placing both tracing point and hatchet on the line and moving the tracing point along it. If the plane of the hatchet is true, the hatchet will follow the line; if not, it will run to one side or the other.

58. Mean Effective Pressure.—To determine the mean effective pressure from the indicator diagram, the first thing to do is to find the length of the diagram. To do this, draw two lines just touching the diagram at its extreme limits,

and perpendicular to the atmospheric line, as illustrated in Fig. 19. The length of the diagram will be the horizontal distance L between these two lines. The area of the diagram in square inches divided by the length in inches gives the mean height, or mean ordinate. This mean ordinate multiplied by the scale of the indicator spring gives the mean effective pressure, or M. E. P.

Let a = area of diagram, in square inches;
L = length of diagram, in inches;
s = scale of spring.

Then, $$\text{M. E. P.} = \frac{a\,s}{L}$$

EXAMPLE.—The area of a certain indicator diagram is 2.17 square inches, the length is 2.9 inches, and the scale of the indicator spring is 120; what is the mean effective pressure?

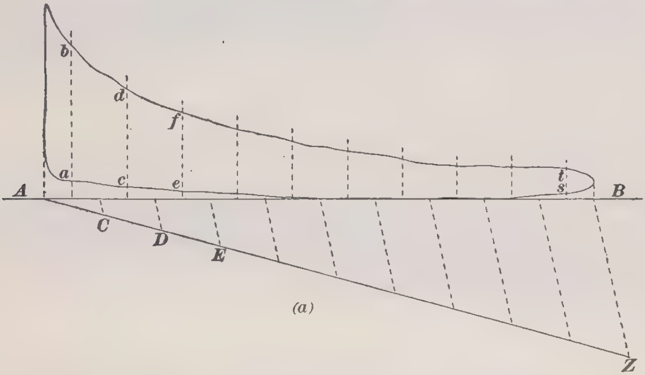
SOLUTION.—Apply the formula, making a=2.17 sq. in., s=120, and L=2.9 in.; then, M. E. P.$=\frac{2.17\times 120}{2.9}$=89.8 lb. per sq. in., nearly. Ans.

59. When a planimeter is not available the following method of finding the mean effective pressure is fairly rapid and accurate: Draw a tangent to each end of the diagram perpendicular to the atmospheric line. Then, accurately divide the horizontal distance between the tangents into ten or more equal parts (ten or twenty parts are the most convenient, but any other number may be used). Indicate, by a dot on the card, the center of each division, and through these dots draw lines parallel to the tangents, and from the upper line to the lower line of the card. On a strip of paper, mark off successively, and with care, the lengths of the lines drawn through the center dots, and between the upper and lower lines of the diagram. The total length thus obtained represents the sum of the lengths of all the lines. Measure this total length in inches, divide by the number of measurements made, and multiply the quotient by the scale of the spring; the result will be the mean effective pressure.

60. A convenient method of dividing the length of the diagram $A\ B$, Fig. 20 (a), into the desired number of parts is to draw the line $A\ Z$, at a small angle to $A\ B$, and then lay off

any convenient length, as *A C*, the required number of times successively, along *A Z*. In this case, *A B* is to be divided into ten equal parts, hence *A C* is laid off ten times successively from *A* to *Z*. Next connect *B* to *Z*, and draw short lines from the points *C*, *D*, *E*, etc., parallel to *B Z* and intersecting *A B*. These points of intersection will divide the line *A B* into the same number of equal parts into which the line *A Z* is divided.

A more convenient method is to locate the middle points of the divisions *A C*, *C D*, *D E*, etc. on *A Z*, and draw lines



(a)

(b)

FIG. 20

from these middle points parallel to *B Z* intersecting *A B* in the middle points of its equal divisions. To find the mean effective pressure, erect perpendiculars at the middle points of these divisions as shown at *a b*, *c d*, *e f*, etc. Find the average length of these lines by laying their lengths off in succession on a piece of paper, as shown at *a′ b′*, *c′ d′*, *e′ f′*, etc. to *s′ t′*, in (*b*). Measure the length from *a′* to *t′*, and divide it by the number of parts into which the diagram was divided. Multiply the quotient by the scale of the spring, and the result will be the mean effective pressure, in pounds per square inch.

61. The experimenter will frequently encounter an engine making a diagram similar to that shown in Fig. 21, with a

loop enclosing the atmospheric line. In such a case, the area of the small loop should be subtracted from that of the larger diagram, before calculating the mean ordinate. The lower line of this loop represents the pressure in the cylinder as the charge is drawn into the engine, and the upper line represents the pressure as the exhaust gases are passing out. Hence, the area of this loop represents the work lost in these two processes. The area of the loop is found by dividing it lengthwise into a number of equal divisions, erecting ordinates at the middle points of the divisions, finding the length of the mean ordinate, and multiplying this mean length by the length

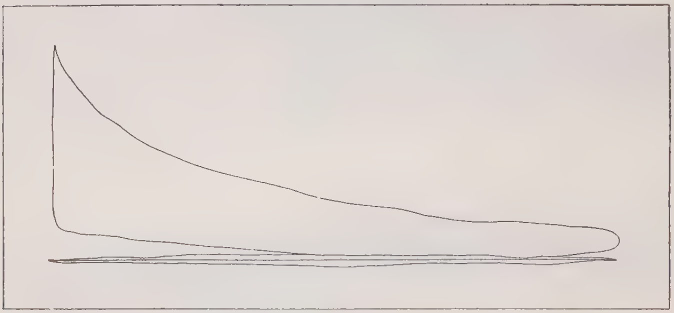


FIG. 21

of the loop. The procedure is the same as that of finding the area of the diagram. The area of the loop may also be determined by the use of a planimeter.

62. Indicated Horsepower.—The indicated horsepower of any gas or oil engine may be calculated by the use of the formula

$$\text{I. H. P.} = \frac{p\,l\,a\,n}{33{,}000}$$

in which p = mean effective pressure, in pounds per square inch;

l = length of piston stroke, in feet;

a = area of piston, in square inches;

n = number of explosions per minute.

As in the calculations for the brake horsepower, the dimensions l and a being the same for all calculations, that portion

of the formula which includes these terms may be computed, and $\frac{l \times a}{33{,}000}$ put equal to a constant c.

EXAMPLE.—In testing a gas engine, it is found that the mean effective pressure is 75 pounds; the stroke of the piston, 6 inches; the area of the piston, 16 square inches; and number of explosions per minute, 70. What is the indicated horsepower?

SOLUTION.—In this example, p=75 lb. per sq. in., l=6 in.=.5 ft., a=16 sq. in., and n=70. Then, substitute these values in the formula and

$$\text{I. H. P.} = \frac{75 \times .5 \times 16 \times 70}{33{,}000} = \frac{42{,}000}{33{,}000} = 1.27 \text{ H. P. Ans.}$$

63. Calculation of Approximate Horsepower.—It is oftentimes desirable to find the approximate maximum horsepower that an engine is or should be capable of developing, without going to the trouble of taking indicator diagrams and determining the mean effective pressure. For this purpose, a number of different formulas have been proposed, all of which are used to a greater or less extent; but it should be clearly understood that they are only approximations, and that the only way to determine exactly what an engine is capable of doing is to make a brake test or find the indicated horsepower by means of diagrams. A suggested formula for finding the approximate indicated horsepower of a four-cycle engine is

$$\text{I. H. P.} = \frac{d^2 p\, l\, r\, n}{1{,}000{,}000} \qquad (1)$$

in which I. H. P. = approximate indicated horsepower;
d = diameter of piston, in inches;
p = mean effective pressure, in pounds per square inch;
l = length of stroke, in inches;
r = number of revolutions per minute;
n = number of cylinders.

The value of the mean effective pressure p is governed by the type of engine and the fuel used. To serve as a guide, the last column of Table II may be used. These values are based on the results of tests made on engines using the various fuels given in the first column. The second column gives the range of pressures at the end of compression for the various fuels.

If the engine is of the two-cycle type, the value of n in formula **1** is multiplied by 2 and the formula becomes

$$\text{I. H. P.} = \frac{d^2 p\, l\, r\, n}{500{,}000} \qquad \textbf{(2)}$$

EXAMPLE.—The diameter of the cylinder of a single-cylinder four-cycle engine is 6 inches, and the length of the stroke is 8 inches. If operated with gasoline at a mean effective pressure of 75 pounds per square inch, it makes 180 revolutions per minute; what is the probable indicated horsepower?

SOLUTION.—In this case, $d^2=6\times6=36$ sq. in., $p=75$ lb., $l=8$ in., $r=180$ R. P. M., and $n=1$. Hence, by substituting in formula **1**,

$$\text{I. H. P.} = \frac{36\times75\times8\times180\times1}{1{,}000{,}000} = 3.89 \text{ H. P., nearly.} \quad \text{Ans.}$$

TABLE II

COMPRESSION AND MEAN EFFECTIVE PRESSURES

Fuel	Compression, in Pounds per Square Inch Absolute	Mean Effective Pressure in Pounds per Square Inch
Kerosene	45 to 70	40 to 80
Gasoline	65 to 95	60 to 100
City gas	45 to 90	45 to 95
Natural gas	115 to 135	70 to 90
Producer gas ...	90 to 150	60 to 100
Blast-furnace gas	140 to 180	50 to 80

64. Still another formula for calculating the probable brake horsepower of one cylinder of a gas or oil engine is

$$\text{B. H. P.} = \frac{d^2 l\, n}{C}$$

in which B. H. P. = approximate brake horsepower;
d = diameter of cylinder, in inches;
l = length of stroke, in inches;
n = number of revolutions per minute;
C = a constant whose value depends on the fuel and the cycle used.

For four-cycle engines using natural gas, $C=16{,}000$; and if the fuel is gasoline, $C=14{,}000$, as an average, although in

exceptional cases, a value of 12,000 may be used, particularly if the engine has large, direct gas passages and small friction. For small two-cycle engines using gas as fuel, $C=12{,}000$; for large two-cycle gas engines, $C=8{,}400$; and for two-cycle gasoline engines, $C=10{,}000$. The formula gives the horsepower for one end of the cylinder only, if the engine is double-acting.

Example 1.—What is the probable brake horsepower of a single-acting four-cycle gasoline engine running at 180 revolutions per minute, if the diameter of the cylinder is 6 inches and the stroke is 8 inches?

Solution.—Apply the formula, substituting $d=6$ in., $l=8$ in., $n=180$ R. P. M., and $C=14{,}000$. Then,

$$\text{B. H. P.}=\frac{6^2\times 8\times 180}{14{,}000}=3.7 \text{ H. P.} \quad \text{Ans.}$$

Example 2.—Find the probable brake horsepower of a double-acting four-cylinder four-cycle gas engine having cylinders 23½ inches in diameter, a stroke of 33 inches, and a speed of 150 revolutions per minute.

Solution.—Apply the formula, making $d=23\frac{1}{2}$ in., $l=33$ in., $n=150$ R. P. M., and $C=16{,}000$; then, the horsepower of one end of one cylinder is

$$\text{B. H. P.}=\frac{(23\frac{1}{2})^2\times 33\times 150}{16{,}000}=171 \text{ H. P.}$$

As a four-cylinder double-acting engine has eight working ends, the probable horsepower of the engine is $171\times 8=1{,}368$ H. P. Ans.

65. Gasoline automobiles are rated in the United States according to the horsepower of the engine. This horsepower is calculated by means of a formula called the **A. L. A. M. formula** and also the **S. A. E. formula,** which is so named because it was adopted by the Association of Licensed Automobile Manufacturers and afterwards by the Society of Automotive Engineers for calculating the rated horsepower of a four-cycle gasoline automobile engine. The formula does not give the exact power delivered under every condition nor the exact theoretical horsepower, but it offers a means of comparison between different engines. It is based on a piston speed of 1,000 feet per minute, an average pressure in the cylinder of 90 pounds per square inch of piston area, and a mechanical efficiency of 75 per cent. The A. L. A. M. formula is

$$\text{H. P.}=\frac{D^2N}{2.5}$$

in which H. P.=horsepower;
D=cylinder diameter, in inches;
N=number of cylinders.

Expressed in words, the horsepower of a four-cycle gasoline automobile engine is equal to the diameter of the cylinder, in inches, multiplied by itself and by the number of cylinders, and the product divided by 2.5.

EXAMPLE.—What is the horsepower rating of a four-cylinder four-cycle automobile engine having cylinders 5 inches in diameter, by the A. L. A. M. formula?

SOLUTION.—The formula is $\text{H. P.}=\frac{D^2N}{2.5}$, and $D=5$ in., and $N=4$. By substituting in the formula, $\text{H. P.}=\frac{5^2\times 4}{2.5}=\frac{25\times 4}{2.5}=40$. Ans.

66. For two-cycle engines, the horsepower may be taken as approximately 1.65 times that of a four-cycle engine of the same dimensions and calculated by the formula of the preceding article. From the fact that there are twice as many explosions per minute in the cylinder of a two-cycle engine as in the cylinder of a four-cycle engine running at the same speed and having the same dimensions, it might be supposed that the power developed would also be twice as great instead of about 1.65 times as great. However, this is not the case because of certain features of the two-cycle engine that tend to lower its horsepower output and cause it to vary more than that of the four-cycle engine. These are, usually, lower compression and lower mean effective pressure due to inefficient scavenging, or cleaning, of the cylinders after each working stroke. There are, of course, exceptional cases where the output of a two-cycle engine is nearly twice that of a four-cycle engine of the same dimensions but the ratio given is usually considered as the average.

HEAT LOSSES

67. The following computations of heat wastes are absolutely necessary only when making a complete heat analysis of the engine. It is always best that such a test be made under the direct supervision of a competent engineer.

The following outline for such an analysis is given for the purpose of explaining the process involved sufficiently to enable one to determine whether such a test is desirable in any specific case.

68. Jacket Losses.—The heat absorbed by the water-jacket is equal to the weight of water passed through the jacket multiplied by the temperature range. The temperature range is the difference between the temperature of the water when it enters the water-jacket and that of the water when it leaves the jacket. For instance, if the temperature of the entering water is 50° and that of escaping water is 180°, the temperature range is $180° - 50° = 130°$. Then, if the weight of the water passing through the jacket in 1 hour is 100 pounds, the heat carried away is $100 \times 130 = 13{,}000$ British thermal units.

69. Exhaust Losses.—To determine the heat carried away by the exhaust gases, the specific heat, as well as the weight of the gas, in pounds per cubic foot, must be known. City gas at atmospheric temperature and pressure weighs, approximately, .078 pound per cubic foot. The specific heat of air is, approximately, .238 at constant pressure; that of city gas may usually, without serious error, be taken as .22. For accurate observations, the specific heat must be ascertained for the particular kind of gas used. These quantities being known, the weight and the specific heat of the mixture, or charge, can be calculated quite readily. The formula for the heat H *per hour* carried away by exhaust is

$$H = s\,w\,q\,(t_1 - t_2)$$

in which s = specific heat of mixture;

w = weight of 1 cubic foot of mixture, in pounds;

q = quantity of mixture exhausted per hour, in cubic feet;

t_1 = temperature of exhaust ascertained by pyrometer;

t_2 = temperature of room.

The volume of the mixture passing through the exhaust is found, approximately, by multiplying the volume displaced by the piston by the number of explosions.

EXAMPLE.—The weight of a cubic foot of the exhaust gases of a certain engine is found to be .068 pound; the specific heat of the mixture is .23; and the number of cubic feet of gas exhausted per hour is 30. If the temperature of the room is 80° F., what is the quantity of heat carried away by the exhaust when the temperature shown by the pyrometer is 350° F.?

SOLUTION.—In this case, $s=.23$, $w=.068$ lb., $q=30$ cu. ft., $t_1=350°$, and $t_2=80°$, and by substituting in the formula,

$$H=.23\times.068\times30\times(350-80)=126.68 \text{ B. T. U. Ans.}$$

70. Heat Absorbed in Work.—The heat absorbed in work is that delivered to the piston in indicated horsepower. The mechanical equivalent of a British thermal unit is 778 foot-pounds; hence, as a horsepower is the capacity to do 33,000 foot-pounds of work per minute, the formula for transforming the indicated horsepower into British thermal units per hour becomes

$$\text{B. T. U.}=\frac{\text{I. H. P.}\times33{,}000\times60}{778}$$

or

$$\text{B. T. U. (per hour)}=2{,}545 \text{ I. H. P.}$$

EXAMPLE.—What is the quantity of heat absorbed in work per hour in an engine the indicated horsepower of which is 25?

SOLUTION.—By substituting in the formula,

$$\text{B. T. U.}=2{,}545\times25=63{,}625. \text{ Ans.}$$

The balance of heat that remains after subtracting the sum of the results of the foregoing three calculations from the heat supplied by the gas is charged to radiation.

EXAMPLES FOR PRACTICE

1. What is the mean effective pressure of an indicator diagram when the area is 1.88 square inches, the length of the diagram is 3.2 inches, and the scale of the spring is 90?

Ans. 52.9 lb. per sq. in., nearly

2. A gas engine makes 5,600 explosions per hour, the piston displacement is .75 cubic foot, and the quantity of gas used per explosion is .1 cubic foot; what is the approximate number of cubic feet of air used per hour?

Ans. 3,640 cu. ft.

3. The diameter of an engine cylinder is 15 inches, and its stroke is 21 inches. The clearance is measured by the method of Art. **38**. The weight of the bucket and water before filling the clearance space is

52.5 pounds, and their weight after filling the space is 7.5 pounds. What is: (*a*) the piston displacement, in cubic feet? (*b*) the clearance, in cubic feet? (*c*) the percentage of clearance?

Ans. { (*a*) 2.15 cu. ft., nearly
(*b*) .72 cu. ft.
(*c*) 33.5 per cent., nearly

4. What is the brake horsepower of a gas engine running at 225 revolutions per minute, when the net pressure it exerts at the end of a 3-foot brake arm is 26 pounds? Ans. 3.34 H. P.

5. Find the indicated horsepower of an engine from which the following results are obtained: mean effective pressure of indicator card, 96 pounds per square inch; length of stroke, 12 inches; diameter of piston, 9 inches; number of explosions per minute, 115.

Ans. 21.28 H. P.

6. How much heat is absorbed in work per hour in an engine of 23.5 indicated horsepower? Ans. 59,807 B. T. U.

7. The exhaust gases of an engine weigh .075 pound per cubic foot, the specific heat of the mixture is .225, the number of cubic feet of gas exhausted per hour is 45, the temperature of the room is 72°, and the temperature shown by the pyrometer is 375°; what is the quantity of heat exhausted per hour? Ans. 230 B. T. U., nearly

8. What is the approximate horsepower of a two-cylinder, four-cycle, gas engine running at 200 revolutions per minute with a mean effective pressure of 75 pounds? The diameter of the cylinder is 10 inches and the length of stroke 16 inches. Ans. 48 H. P.

INDICATOR DIAGRAMS

71. The determination of the mean effective pressure is neither the only nor the most important use of the indicator diagram; it also serves to show what is taking place in the cylinder during the time that the diagram is being produced. An engineer thoroughly familiar with the operation of the gas engine can usually locate a defect much more quickly from an examination of its diagram than from a tedious examination of the engine itself.

The diagrams shown in Fig. 22 are, with one exception, copies of actual diagrams. Diagram *A* was taken from a Hornsby-Akroyd oil engine using ordinary kerosene oil. The

cycle is the same as that of the Otto gas engine, and the diagram is shown as an excellent example of what a good gas-engine diagram should be. That there is very little resistance in the admission and exhaust passages is shown by the curved lines that lie close to and just above and below the atmospheric line $x\ y$. These show but little rise or fall of pressure.

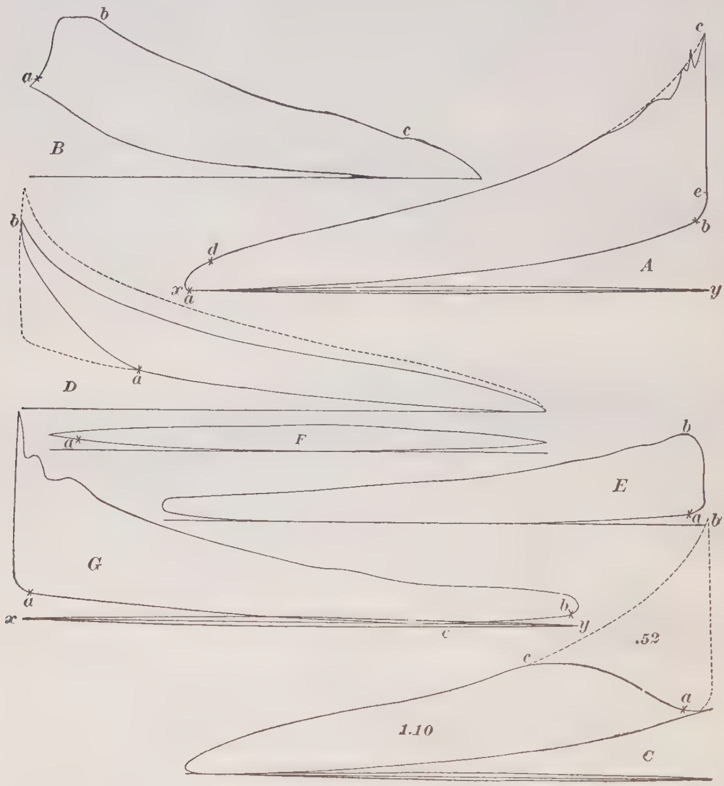


Fig. 22

The curve above the atmospheric line, if high, would show resistance in the exhaust passages, and that below the atmospheric line would show resistance in either the gas passages, the air passages, or both.

72. Compression begins at *a*, diagram *A*, Fig. 22, and the pressure of the charge is gradually increased until, just before

the piston reaches the end of the compression stroke, the charge is ignited at *b*. The point *b* of ignition is shown by the sudden change in the direction of the compression line. The advantage gained by ignition taking place just before the completion of the compression stroke is shown by the line *e c*. This line is at right angles to *x y*, proving conclusively that the charge was fully inflamed before the piston started on its forward stroke. This is as it should be; that is, the point of maximum pressure is at the beginning of the stroke, just before the piston starts forwards.

The ragged appearance of the diagram at the beginning of the forward stroke is not due to any fault of the engine, but to the vibration of the indicator spring, caused by the rapid rise of pressure from *e* to *c*. The curve would otherwise be quite regular from *c* to *d*, as shown by the dotted lines. The fall from *c* to *d* is gradual, and the form of the diagram after release at *d* shows a quick-opening exhaust valve and very little resistance in the exhaust passages.

73. An example of late ignition is shown in diagram *B*, Fig. 22. Ignition takes place at *a* just after the crank has passed the center. The result is that the initial pressure is much below what it should be, and the maximum pressure occurs too late in the stroke. The effect of this derangement is shown more distinctly in diagram *C*, where ignition takes place much later in the stroke. The dotted line shows the shape of the diagram obtained when ignition takes place at the proper point, the area *a b c* being the measure of the power lost. The areas are indicated by the figures on the diagram, .52 being the area, in square inches, of *a b c*, and 1.10 that of the actual diagram. This shows that very nearly one-third of the available power has been lost through faulty ignition.

74. Bad as late ignition is, too early firing is no better, because it checks the speed of the engine and causes an injurious pounding. It may even cause a reversal of the engine at low speeds and light loads. A diagram illustrating the effect of too early ignition is shown at *D*, Fig. 22. The excessive back pressure from *a* to *b* is very evident. Too early ignition also

gives the cylinder walls a chance to carry off an excessive amount of heat, owing to the slow speed of the piston at the end of the stroke. The diagram produced lies inside that obtained when the ignition is properly timed, as shown by the dotted lines. The loss of work is shown by the difference in the areas of the two diagrams. Fortunately, this is a condition promptly made evident by the behavior of the engine, and is soon remedied.

75. Care must be taken that the diagrams produced by badly timed ignition are not confused with those produced by weakened mixtures. Examples of the latter are shown in the indicator diagrams *E* and *F*, Fig. 22. In each of these diagrams, ignition takes place at *a*, but in diagram *F* the maximum pressure is not reached until the piston is at the middle of its stroke. In *E*, the maximum pressure occurs a trifle late, but it should be noted that the line *a b* is approximately at right angles to the atmospheric line. The later occurrence of the maximum pressure is due, not to faulty timing of the ignition, but to the fact that flame propagation is slower in weak mixtures, and particularly when the compression pressure is low. The engine from which these diagrams were taken is governed by throttling both the gas and the air.

76. Diagram *G*, Fig. 22, indicates very clearly that the exhaust passages are obstructed. The point *b* should be on the atmospheric line *x y*, as shown in *A* at *x*. Instead, the line of the diagram does not reach *x y* until the piston returns to *c*. This may be due to a sluggish opening of the exhaust valve or to constricted exhaust passages. Some forms of exhaust mufflers will cause the production of such a diagram.

Several of these defects may occasionally appear on one diagram. They are all more or less detrimental to the proper performance of the engine. The remedy will usually suggest itself in every case. Quite often, the remedy consists in the adjustment of the ignition mechanism or the proper setting of the valves. Sometimes, however, it will not be possible to remedy the defect except in a new design.

77. When desired, the expansion curve may be compared with a theoretical curve by drawing a curve according to the law $p v^n$ = a constant, from a point on the expansion curve where the combustion is complete. The exponent n should be so chosen that the resulting curve will represent the average practice of engines of the type under consideration. In the absence of a more accurate value, the value of n for adiabatic expansion of air, namely, 1.405, is sometimes used. A comparison of the theoretical with the actual curve may reveal defects in the expansion curve that could not readily be detected with the eye. It must not, however, be supposed that the theoretical and actual curves should entirely coincide.

78. The diagram shown in Fig. 23 was taken with an indicator using a light spring and fitted with a safety stop,

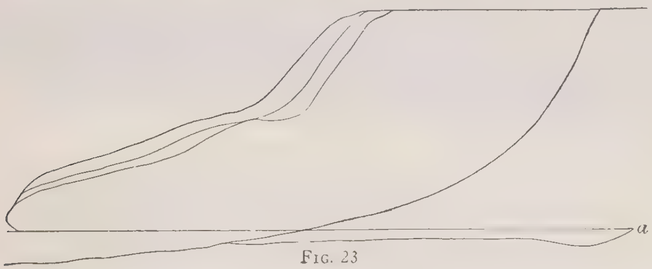


FIG. 23

so that the higher pressures are not recorded. Such a diagram is called a *stop-motion diagram.* The sudden drop of the admission line at the point *a* shows that the admission valve opens too late. The horizontal line *b*, at the top of the diagram, is caused by the stop limiting the vertical travel of the pencil when it rises to this point. The diagram cannot, therefore, be used for determining the mean effective pressure.

79. When an engine is governed by the hit-or-miss method, there will be idle strokes during which the contents of the cylinder will be compressed and expanded without opening the valves. If there are no leaks and the cylinder is not cooled too rapidly the gas in the cylinder will give out practically as much work on the expansion stroke as was expended in compressing it; in other words, the curves of compression and expansion

on the idle strokes will lie very close together, or even may coincide. A diagram showing the curves of compression and expansion on the idle strokes is given in Fig. 24. The upper

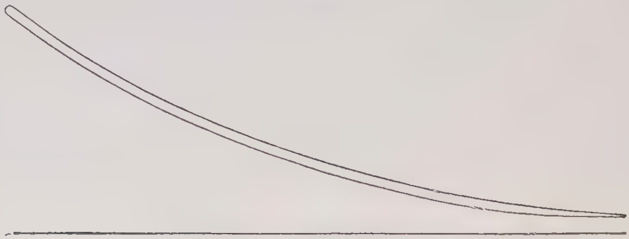


FIG. 24

line is the compression curve and the lower one the expansion curve. The area between them represents lost work and may be due to leakage or to cooling of the gases, or to both.

If the charge is ignited too early on the compression stroke, preignition is said to occur. If the explosion due to preignition is strong enough to stop the piston and force it in the opposite direction, thus reversing the direction of rotation of the engine, the action is called a back-kick. Sometimes, due to slow burning of the charge in the cylinder, the incoming fresh charge may be ignited by the lingering flame, with the result that an explosion will occur in the intake manifold and the carbureter.

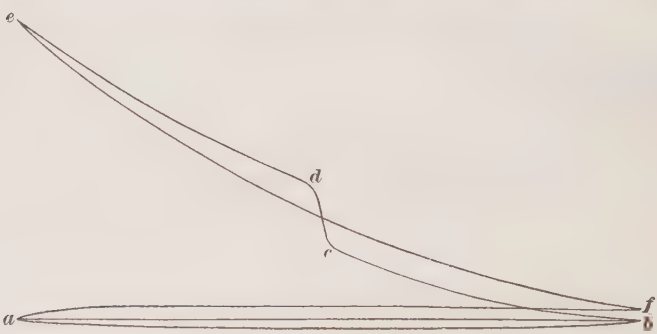


FIG. 25

This is known as a back-fire. A back-kick is very often accompanied by back-firing, which accounts for the frequent confusion of these two terms.

80. The diagram shown in Fig. 25 indicates preignition of the charge during compression. The lower line from *a* to *b* represents the suction stroke. Compression takes place from *b* to *c*, at which point the charge is preignited, followed by a sudden rise of pressure to *d*, after which compression is continued to *e*. On the next stroke, the burned gases simply expand to *f* and are discharged from the cylinder, as indicated by the exhaust line *f a*.

In case back-firing occurs, a diagram similar to that shown in Fig. 26 may be produced. Suction begins at *a*, but before it is completed the gas is fired at *b*, causing the pressure to rise to *c* and then fall to *d* as the piston continues to move. From *d* to *e* compression of the burned gases occurs, and expansion from *e* to *f* along practically the same line. It will be observed

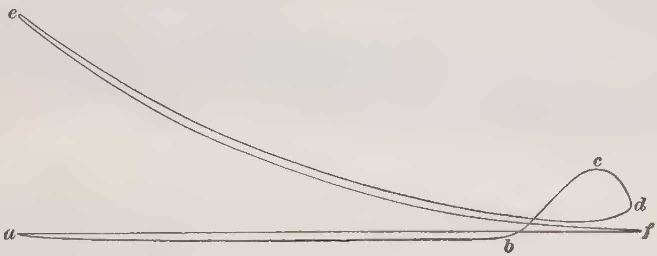


FIG. 26

that there is little or no power developed; in addition, the next succeeding power stroke is apt to be missed, because the back-firing while the inlet valve is open drives burned gases back into the suction pipe, so that the charge admitted on the next suction stroke is of such poor quality that it will not ignite.

81. The forms of the lines of a diagram may be more carefully investigated by taking stop-motion diagrams, which are simply diagrams taken with a very light spring, the indicator being fitted with a stop that prevents the spring from being compressed beyond a safe limit. The advantage of taking a stop-motion diagram with a very light spring is that the suction and exhaust lines are shown to a large scale and thereby indicate faults in the valve action that could not be detected if a strong spring were used. A light-spring diagram is shown in

Fig. 27. Suction takes place from *a* to *b*, with only about 1 pound below atmospheric pressure, showing that the gas

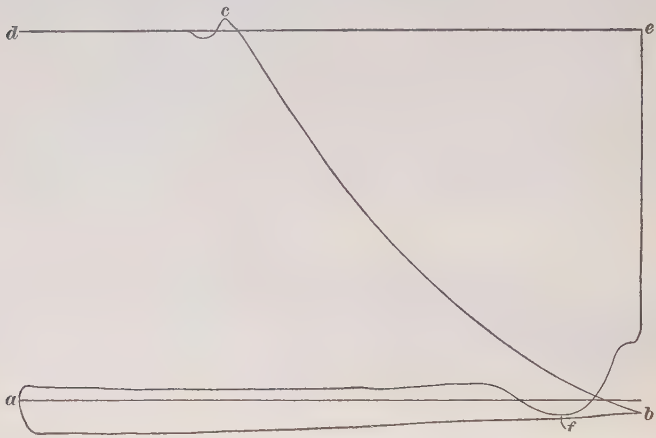


Fig. 27

passages are not restricted. Compression occurs from *b* to *c*, at which point the stop-motion acts to prevent further compression of the spring, resulting in a practically straight line from *c* to *d* for the remainder of the compression. The pressure after explosion is so great that the spring is held against the stop during the whole of the expansion stroke from *d* to *e*.

Fig. 28

When the exhaust valve opens, the pressure drops rapidly to *f* and exhaust then occurs, at very little above atmospheric pres-

sure, from f to a, showing that the exhaust ports and passages are of ample area.

82. Indicator diagrams taken from the cylinders of Diesel engines are of value in showing faulty combustion and valve timing; but the diagrams themselves must be taken with accurate instruments properly attached and operated. One of the

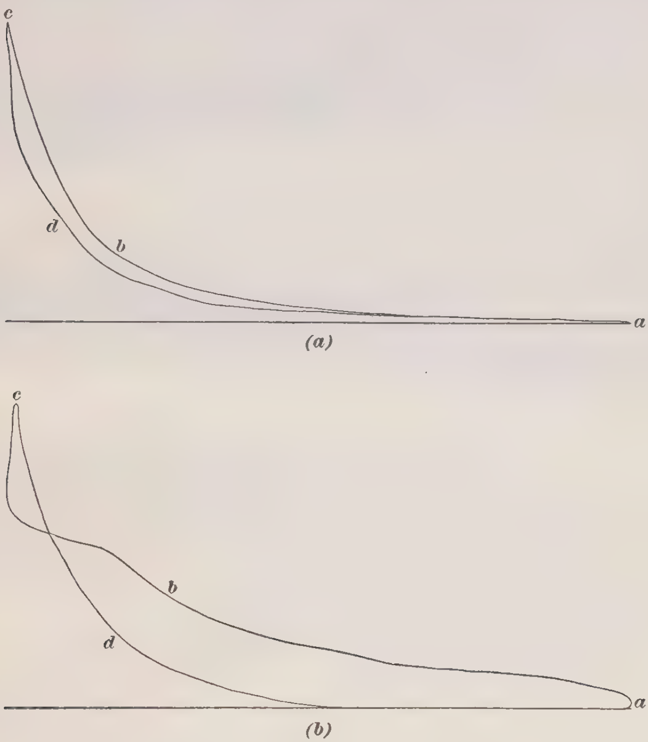


Fig. 29

principal points to be determined is whether there is any loss of compression by leakage. To this end, a diagram should be taken from each cylinder without allowing the fuel valve to open, the engine being driven by the energy stored in the flywheel. Theoretically, the diagram should be similar to that shown in Fig. 28, in which $a\ b$ is the suction line, $b\ c$ the compression line, $c\ b$ the expansion line, and $b\ a$ the exhaust line.

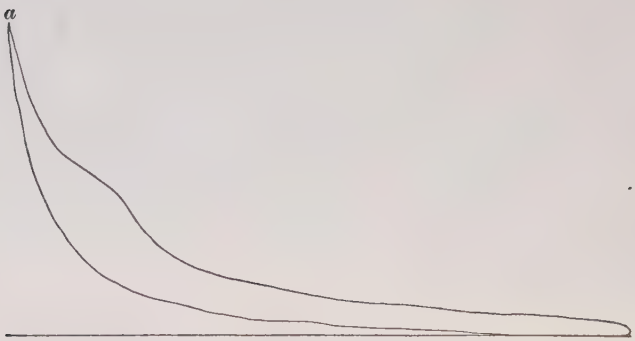


Fig. 30

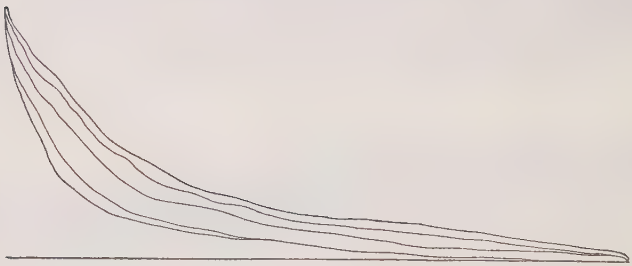
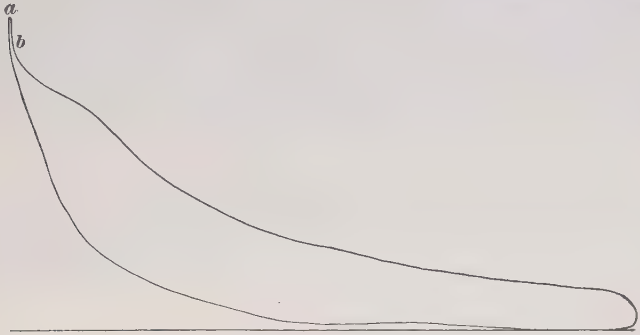


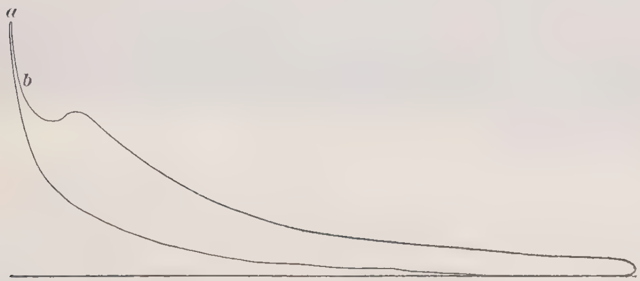
Fig. 31

Fig. 32

With no leakage, the compression and expansion lines will practically coincide, except, perhaps, for a slight lowering of



(a)



(b)

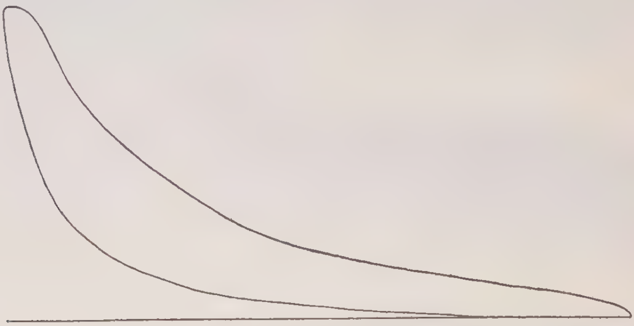
Fig. 33

the expansion line due to loss of heat. If there is leakage, the diagram will take a form similar to Fig. 29 (*a*) or (*b*), depend-

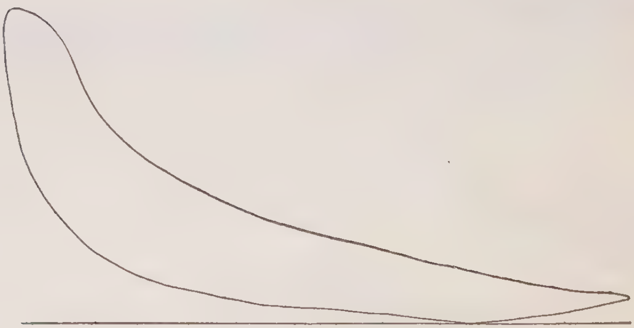
Fig. 34

ing on the amount of leakage. In each of these diagrams, *a b c* is the compression line and *c d a* the expansion line.

83. The compression pressure in the Diesel engine is about 500 pounds per square inch. If it is carried much beyond this, the indicator diagram will run up to a point, as at *a*, Fig. 30, instead of being nearly flat at the top, as in the normal diagram for this type of engine. The diagram shown in Fig. 31 indicates that the fuel valve leaks, resulting in a wide variation in the amount of fuel injected during a number of cycles.



(*a*)



(*b*)

Fig. 35

This form of card is apt to be produced, also, when the engine is run under very light load and the governor control is not too accurate. If the injection pressure of the air varies, the diagram will appear somewhat as shown in Fig. 32. If the fuel valve is late in opening, the diagram will have a form like that shown in Fig. 33 (*a*) or (*b*). At the end of compression, expansion takes place from *a* to *b* before the fuel is

injected, and so the expansion line follows the compression curve to the point *b* where combustion begins. The diagram in Fig. 34 indicates protracted combustion, which caused the hump at *a* in the expansion curve. The delayed combustion was due to the collection of a small quantity of fuel in a pocket in the combustion chamber. The combustion chamber should be free of pockets in which the fuel may collect.

84. The form of the exhaust end of the diagram should be examined, also. The exhaust valve should open just before the end of the expansion, so that part of the drop in pressure occurs before the piston reaches the end of its stroke and the remainder just after it starts on the next stroke. This will produce a rounded exhaust line at the toe of the diagram. If the exhaust valve opens too soon, the toe will be pointed as in Fig. 35 (*a*); and if it opens too late, the toe will be of the shape shown in (*b*). With the exhaust valve opening too late, the running of the engine is apt to be noisy. The form of the suction line and the exhaust line may be investigated by taking stop-motion diagrams.

EFFICIENCY

85. The **efficiency** of any engine is the ratio of the work actually performed to the work contained in the source from which the power is derived. This ratio is also often called the **total efficiency;** and, in the case of a gas engine, it may be obtained by dividing the work measured as the brake horsepower by the total work, or energy, in the gas used, for the same length of time. A convenient way to do this is to reduce the brake horsepower to equivalent British thermal units and divide the result by the British thermal units given up by the quantity of gas actually used in 1 minute. The total efficiency is seldom used in actual practice. There are, however, two other efficiencies that are frequently determined, namely, the *thermal efficiency* and the *mechanical efficiency*.

86. Thermal Efficiency.—The **thermal efficiency** is determined by dividing the heat absorbed by the engine by

that supplied by the gas. The result is usually written as a percentage. In the theoretically perfect engine, the heat absorbed in work depends directly on the drop in the absolute temperature of the gas from the explosion to the exhaust temperature; and the total heat in the gas depends, in the same way, on the absolute temperature of the gas at explosion. For this reason, the formula for thermal efficiency is usually written

$$E_t = \frac{T_1 - T_2}{T_1}$$

in which E_t = thermal efficiency;
T_1 = absolute temperature of gas at explosion;
T_2 = absolute temperature of gas at exhaust.

The thermal efficiency of any gas engine is the total efficiency of a perfect engine working between the same initial and final temperatures, because the perfect engine would utilize all the heat given up by the gas. Hence, the thermal efficiency is sometimes called the *efficiency of the perfect engine.*

EXAMPLE.—If the initial temperature of a gas at explosion is 2,900° F. and the exhaust temperature is 1,682° F., what is the thermal efficiency of the engine?

SOLUTION.— $T_1 = 2{,}900° + 460° = 3{,}360°$; $T_2 = 1{,}682° + 460° = 2{,}142°$. By substituting in the formula,

$$E_t = \frac{3{,}360 - 2{,}142}{3{,}360} = .3625, \text{ or } 36.25 \text{ per cent. Ans.}$$

87. Mechanical Efficiency.—The **mechanical efficiency** of an engine is the ratio of the brake horsepower to the indicated horsepower. The mechanical efficiency E_m is usually expressed by the formula

$$E_m = \frac{\text{B. H. P.}}{\text{I. H. P.}}$$

The difference between the indicated horsepower and the brake horsepower represents the power required to drive the engine, and is used to overcome the friction of the engine, so that, if the engine were running without load, the power required to run it would represent the **friction load,** or friction horsepower, of the engine, or I. H. P. − B. H. P. Hence, it is easy to see that the lighter the load on an engine, the less the mechanical efficiency will be.

EXAMPLE.—(*a*) What is the friction load of an engine when the I. H. P. is 25 horsepower and the B. H. P. is 22 horsepower? (*b*) What is the mechanical efficiency?

SOLUTION.—(*a*) Friction load=I. H. P.−B. H. P.=25−22=3 H. P. Ans.

(*b*) $$E_m=\frac{\text{B. H. P.}}{\text{I. H. P.}}=\frac{22}{25}=88 \text{ per cent.} \quad \text{Ans.}$$

Average mechanical efficiencies have been found to be about as given in Table III. An engine using a lean gas (that is, a gas of poor quality) and high compression will show a lower mechanical efficiency than one using rich gas and moderate compression.

TABLE III

AVERAGE MECHANICAL EFFICIENCIES

Size of Engine Horsepower	Four-Cycle Engine	Two-Cycle Engine
4 to 25	.74 to .80	.63 to .70
25 to 500	.79 to .81	.64 to .66
500 upwards	.81 to .86	.63 to .70

EXAMPLES FOR PRACTICE

1. The temperature of a gas at explosion, in a gas engine, is 2,740° F., and the temperature of the exhaust is 1,370° F.; what is the thermal efficiency? Ans. 42.81 per cent.

2. The indicated horsepower of a gas engine is 237, and the delivered horsepower is 215; what is its mechanical efficiency? Ans. 90.7 per cent.

SHOP TESTS

88. When the design of a gas engine has been decided on, and engines are built according to the design, each one is tested in the shop of the makers before shipment to the purchaser. In such cases, it is not customary to make a very exact test, as this is unnecessary for the purpose of determining whether the performance of the engine comes up to the standard. The points to be determined by the test are: (*a*) whether the engine runs without undue friction or over-

heating, and without leakage at the piston or valves; (*b*) whether the valves and ignition are properly timed; and (*c*) whether the engine uses more than the guaranteed quantity of fuel per horsepower per hour, and whether it comes up to the guaranteed maximum horsepower. In the following articles is given an outline of the procedure adopted for tests of this kind by one of the largest manufacturers of gas engines.

89. Before the engine reaches the testing stand, the piston has been fitted as accurately to the cylinder as possible, so that there is little or no possibility of the gases blowing past the piston. It is, however, almost impossible to get a new piston so that it will run quite tightly for any considerable length of time without expanding. This makes it seize the cylinder in spots, causing a knocking sound, which is due to the motion of the connecting-rod on the crankpin and wristpin. Of course, this motion is very slight, and is only the necessary amount of freedom in the bearings; however, it makes quite a noise. As soon as this knocking develops, the engine is stopped, and the piston taken out of the cylinder and carefully examined. The high spots, which are now very apparent, are carefully dressed down with a smooth file. This is done very gradually, so as to avoid taking off too much, as to a certain extent the makers depend for tightness on the piston as well as on the rings. Generally, it is necessary to remove and dress down the piston three or four times in this manner before it reaches that condition where it can be operated continuously under full load.

90. The indicator is used on every engine, but only for determining the adjustment of the valves and the timing of the ignition. When engines are being constantly tested and the number of indicators available is limited, it is found impracticable to keep the indicators in such condition that their results are trustworthy as a means of determining the horsepower; hence, it is customary to determine the power by means of the Prony brake. When an engine is governed on the hit-or-miss principle a counter may be connected to the fuel inlet valve, thus recording the number of charges taken in.

91. When the engine is to be run with illuminating gas, the fuel consumption is determined by a meter that registers to hundredths of a cubic foot. The engine is generally tested at somewhat above the rated load, though still, perhaps, below its maximum load. The gas consumed per hundred charges is measured and the number of charges per minute counted when the engine is running under the constant test load, and proper deduction made for charges missed. Engines built to use gasoline are tested for fuel consumption by drawing the gasoline from a graduated bottle; and, since the consumption is practically constant under constant load, it is found that a comparatively short test, using up 1 or 2 gallons of gasoline, according to the size of the engine, is sufficient.

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NOTE.—In this volume, each Section is complete in itself and has a number. This number is printed at the top of every page of the Section in the headline opposite the page number, and to distinguish the Section number from the page number, the Section number is preceded by a section mark (§). In order to find a reference, glance along the inside edges of the headlines until the desired Section number is found, then along the page numbers of that Section until the desired page is found. Thus, to find the reference "Air pressure, §22, p8," turn to the Section marked §22, then to page 8 of that Section.

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